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# NASA/MSFC FY-80 ATMOSPHERIC PROCESSES RESEARCH REVIEW

Summary of review held June 3-5, 1980,
Huntsville, Alabama

Compiled by Robert E. Turner
Space Sciences Laboratory

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Prepared By

NASA - George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

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16. ABSTRACT

A review of the NASA/MSFC FY-80 Atmospheric Processes Research Program was held in Huntsville, Alabama, June 3-5, 1980. This report contains the research project summaries, in narrative outline form, supplied by the individual investigators together with the agenda and other information about the review.

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## ACKNOWLEDGMENTS

The productive inputs and comments from the participants and attendees in the Atmospheric Processes Research Review contributed very much to the success of the review. The opportunity provided for everyone to become better acquainted with the work of other investigators and to see how the research relates to the overall objective of NASA's Atmospheric Processes Research Program was an important aspect of the review. Appreciation is expressed to all those who participated in the review. The organizers trust that participation will provide each with a better frame of reference from which to proceed with the next year's research activities.

# PREFACE

Each year NASA supports research in various disciplinary program areas. The coordination and exchange of information among those sponsored by NASA to conduct research studies are important elements of the program. The NASA Office of Space and Terrestrial Applications, via an Application Notice (AN), has invited interested investigators throughout the country to communicate their research ideas for the topics identified in the AN. The proposals in the Atmospheric Processes Research area selected and assigned to the NASA Marshall Space Flight Center's (MSFC's) Atmospheric Sciences Division for technical monitorship, together with the research efforts included in the FY-80 MSFC Research and Technology Operating Plan (RTOP), were the source of principal focus for the participants in the NASA/MSFC FY-80 Atmospheric Processes Research Review held June 3-5, 1980, in Huntsville, Alabama.

The principal purpose of the review was to provide those having major research activities sponsored by NASA's Atmospheric Processes Research Program and assigned to MSFC's Atmospheric Sciences Division an opportunity to meet and discuss their programs and future plans. In addition, the review provided NASA Headquarters and MSFC Research Program Managers with a current status report plus suggestions for future research for use in developing program needs. The principal managers involved were: Dr. Shelby Tilford, Atmospheric Processes Research Program and Upper Atmosphere Research Program; Dr. James Dodge, Severe Storms and Local Weather Research Program; Mr. John Theon, Global Weather Research Program; and Dr. William W. Vaughan, MSFC Atmospheric Processes Research Program. Dr. Robert Turner served as the coordinator for the research review.

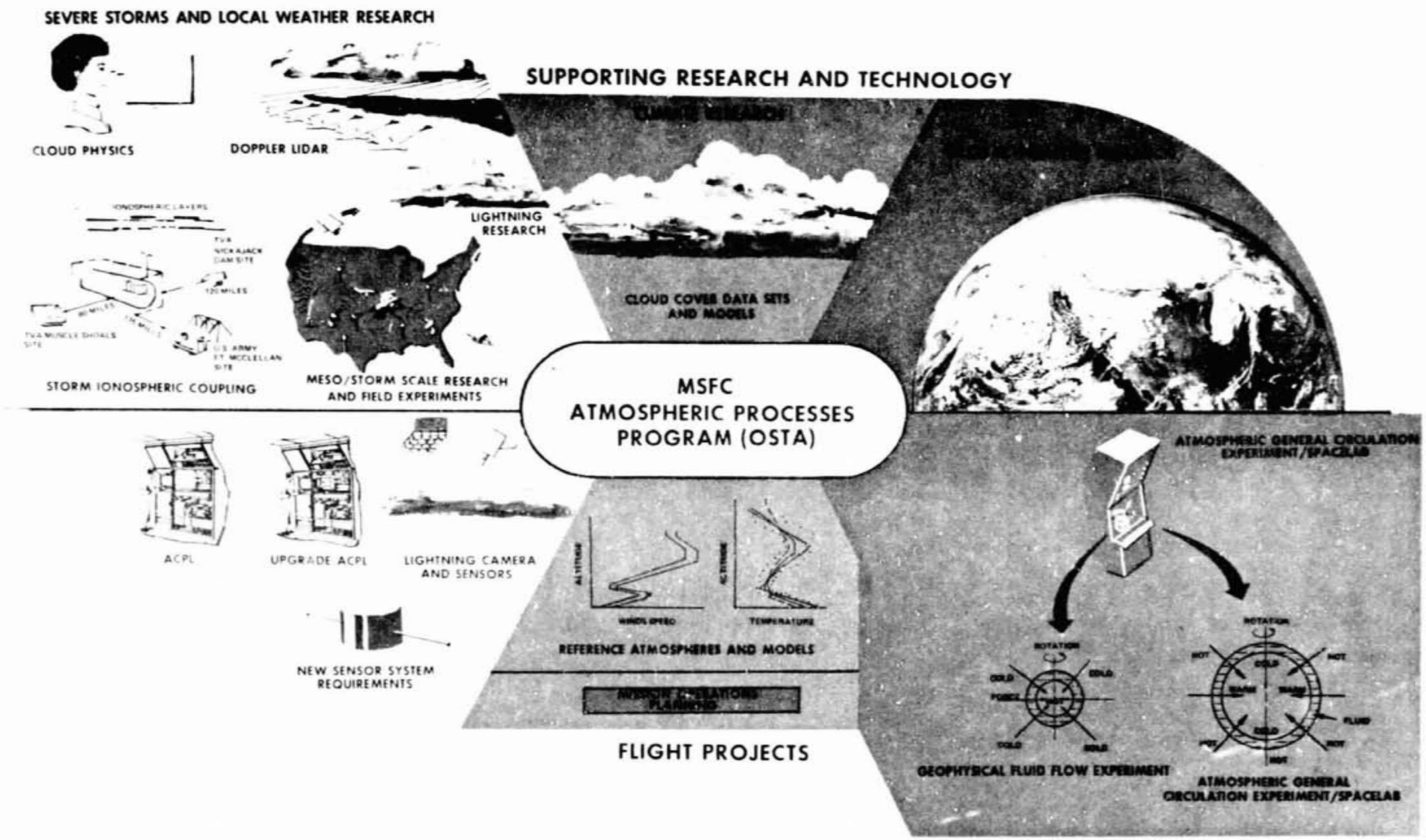
Three general areas of NASA's Atmospheric Processes Research Program were included in the review: Global Weather, Upper Atmosphere, and Severe Storms and Local Weather. The final titles of the individual presentations varied depending on the particular emphasis of the designated speaker. The technical aspects of the research efforts were stressed, and the individual presentations were developed to provide the rationale for recommendations on the coming year's research. The agenda for the review and a list of attendees are included as Appendices A and B of this report.

There were many research topics to cover, and it was important that each person discipline his presentation time. While the time available did not permit all research topics to be covered, the majority were accommodated during the 3-day review. The organizers endeavored to make the review just that—a review of the major aspects of the sponsored research activities relative to the NASA program aims. The review was planned to be informal to permit the maximum exchange of information among the participants, insofar as practical; and a research team spirit did prevail and was further enhanced by discussions. To provide for a follow-up by the various participants and attendees, each investigator was requested to prepare a brief narrative outline of his research project. The investigators' unedited outlines are assembled in this report.

It was recognized that the scopes of individual research efforts comprise a wide range. Some are very modest or have been under way for only a short period of time, whereas others are larger or represent nearly two years of activity. However, the opportunity to learn what each investigator is doing and to develop the team relationship necessary for a meaningful research program were considered most important. In this context, it is appropriate to restate the aim of NASA's Office of Space and Terrestrial Applications research program; it is toward this aim that all research sponsored by the program should be directed. It is summarized as follows:

> The aim of the research program of NASA's Office of Space and Terrestrial Applications is to establish useful applications of space techniques/technology to improve conditions here on Earth. This aim is pursued through partnership efforts with responsible mission agencies and private entities. In order to establish useful applications and develop additional techniques and capabilities, research is conducted within NASA and with other Government agencies, academic institutions, and private organizations. NASA approaches the specific near-term objectives through its discipline programs (which include Atmospheric Processes).

William W. Vaughan
Chief, Atmospheric Sciences Division
Space Sciences Laboratory
NASA Marshall Space Flight Center

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# SECTION I. GLOBAL WEATHER RESEARCH

The NASA program of Global Weather Research is to develop an improved capability for making global observations of meteorologically important parameters in order to increase the understanding of the complex processes which influence the large-scale behavior of the atmosphere.

John Theon

# THE GEOPHYSICAL FLUID FLOW EXPERIMENT

**Investigators:**


| | |
|---|---|
| Prof. John Hart | Department of Astrogeophysics, Univ. Colorado. 303-492-8568 |
| Prof. Juri Toomre | Department of Astrogeophysics, Univ. Colorado. 303-492-7854 |
| Dr. Peter Gilman | High Altitude Observatory, Boulder, Colorado. 303-494-5151 |
| Mr. Neil Hurlburt | Department of Astrogeophysics, Univ. Colorado. |
| Mr. Brian Feidler | Department of Astrogeophysics, Univ. Colorado. |


Scope of Research:

The Geophysical Fluid Flow Cell (GFFC) is a laboratory fluid dynamics experiment designed to study flow in a rotating spherical shell, differentially heated between inner and outer spherical surfaces. A large ac voltage is applied across the dielectric fluid contained within the spherical gap and in the absence of an external gravitational field this leads to a purely inward pointing radial acceleration (spherical geopotential). Thus such an experiment is a physical laboratory analog of planetary scale geophysical flows on rotating planets and the sun, where buoyancy and Coriolis forces both act to create atmospheric or oceanic motions. The GFFC was designed with the primary goal of aiding our understanding of large scale thermal convection; the form of the dominant large eddies, the eddy fluxes of heat and momentum, and the manner in which they interact with zonal circulations producing jet streams and/or differential acceleration. The research program of our group is oriented towards the scientific support of the GFFC experiment to fly on Spacelab III. We are charged with the selection of experiment parameters, data reduction and analysis, comparison of experimental results with theory, and interpretation of the laboratory flows in terms of their implications for planetary circulations.

Results in FY 80:

1. Linear stability theory was used to estimate the external parameters (heating,rotation, etc.) at which axisymmetric multi-cell convection or non-axisymmetric convection should appear in the experiments. These theoretical results were then used to formulate both test cases for terrestrial laboratory runs of the GFFC and Spacelab I radial gravity experiments.

2. A digital-computer based image processing system was designed and assembled. It reads the 16mm data film output from the GFFC experiment and will generate reduced plots of fluid temperature and velocity that can be directly compared with theory. A significant amount of effort was devoted to constructing software to align the GFFC images and to decode the LED binary coded information located along the edges of each frame.

3. Theories predicting the thermal distribution in the spherical bounding surfaces of the GFFC were completed. These indicated there would be a negligible amount of feedback between the convection cells in the fluid and the instrument thermal control loops. Also it was verified that aside from the control loops, the finite conductivity of the boundaries would have even smaller influence on convection in the working fluid.

Current Focus:

The research emphasis is currently two-fold. First we are extending our linear stability theory of the preferred convection modes in the experiment to the non-linear regime through the use of a 3-dimensional numerical model. Of particular interest is the stability of axisymmetric multi-cellular disturbances to non-axisymmetric perturbations. Also effects of compressibility and latent heat release on planetary scale rotationally affected convection are being considered to aid the extension of laboratory results to geophysical situations. Secondly, we are continuing the programming of the primary data reduction image processor. Results from instrument tests and ground based experiments are being used to effect a calibration of the GFFC shadowgraph.

FY81 Program:

It is planned to continue numerical solutions of the full non-linear hydrodynamic equations for thermal convection forced by radial and north-south temperature distributions on the boundaries. The goal here is to construct a regime diagram in the Rayleigh-Taylor number parameter space that can be compared with laboratory experiment. Also, we shall initiate a study of convection driven between two differentially heated spherical shells in a uniform vertical gravity field. This study shall include a set of terrestrial laboratory experiments using the GFFC, along with associated analytical and numerical theory. It has two goals; an increased understanding of this convection configuration which is of interest in certain engineering problems involved with solar heating and chemical processing, and more importantly to provide a baseline theory-experiment interaction that will facillitate data analysis and interpretation from the zero-gravity laboratory experiments to be run on Spacelab III.

**Title:**

Convection Driven by Radial and Latitudinal Temperature Gradients in a Rotating Fluid: Planetary Circulations and GFFC Experiment Planning

**Investigators:**

Dr. Peter A. Gilman
Dr. David H. Hathaway
Mr. Jack Miller
NCAR
P.O.Box 3000
Boulder, CO 80307
303-494-5151

Prof. Juri Toomre
Department of Astro-Geophysics
University of Colorado
Boulder, CO 80302
303-492-7854

Significant Accomplishments FY-80:

We have completed a linear stability analysis for convection driven by radial and latitudinal temperature gradients in a rotating, plane parallel layer of fluid. We find that the thermal wind shear driven by the latitudinal temperature gradient can produce a preference for axisymmetric convective rolls provided this gradient exceeds some value which depends upon the rotation rate and the latitude. While the dynamical characteristics of these rolls are similar in many respects to those of Jupiter's cloud bands the results of such calculations as suggestive at best due to the severe approximations involved.

Hathaway has developed a nonlinear code which examines the three dimensional and time dependant convective motions in a plane parallel layer of fluid under the same conditions investigated in the linear study. The preliminary results indicate that the findings of the linear study do extend to the nonlinear regime but that more complicated flows are produced when the motions are fully developed.

We have produced two altered versions of Gilman's code for convection in rotating spherical shells. The first (the Jupiter deck) includes a latitudinal temperature gradient and has slippery boundaries to better represent planetary conditions. The second (the Lab deck) also includes a latitudinal temperature gradient but has rigid boundaries and the 1/r5 gravity appropriate for the GFFC experiment. Preliminary results from the Jupiter deck indicate that the plane parallel studies provide reasonably accurate predictions for the onset of the axisymmetric modes provided the thermal wind dominates the flow. However at the smaller rotation rates a meridional circulation replaces the thermal wind and precludes the presence of any axisymmetric rolls. When the axisymmetric rolls are produced they drive high latitude jets similar to those observed on Jupiter but the non-axisymmetric modes appear to be required to produce the equatorial jet.

Current Focus of Research Work:

We are continuing our nonlinear calculations in both plane parallel and spherical geometries. We hope to determine the conditions under which the resulting circulations most resemble those on Jupiter if indeed such circulations can be realistically produced under these conditions.

Plans for FY-81:

We will continue these calculations in an effort to produce Jovian type circulations and to determine appropriate parameter values for use in the Lab deck. The Lab deck will then be used to simulate the flows expected in the GFFC experiment and thus provide possible senarios for running that experiment.

Recommendations for New Research:

It would be useful to also produce a code which would look at compressible convection under similar circumstances. Although the Boussinesq approximation used in the present calculations is appropriate for the GFFC experiment it cannot be realistically employed for actual simulations of deep convective motions on a planet like Jupiter. Recent advancements in the theory of compressible convection indicate that additional phenomena can occur which are unpredicted by the incompressible models. Thus, if we are to fully understand the dynamics of deep planetary atmospheres and to use the results of the GFFC experiment for interpreting the observed motions we also need to model the more realistic compressible flows.

Title: The Geophysical Fluid Flow Cell (GFFC)

Research Investigator(s) Involved:

Dr. John Hart, University of Colorado
Dept. of Astrogeophysics, Boulder, CO

Dr. Juri Toomre, University of Colorado
Dept. of Astrogeophysics, Boulder, CO

Dr. Peter Gilman, National Center for Atmospheric Research/High Altitude Observatory, Boulder, CO

Dr. George H. Fichtl, NASA Marshall Space Flight Center, Marshall Space Flight Center, AL 35812

Dr. William Fowlis, NASA Marshall Space Flight Center, Marshall Space Flight Center, AL 35812

Significant Accomplishments FY80:

The GFFC is an instrument which will be used to study spherical convection processes in the context of geophysical fluid dynamics of planetary atmospheres. The GFFC instrument will be used to study convection processes in spherical shells in the context of large-scale dynamics of hydrostatically unstable atmospheres and stellar interiors. The GFFC contains a 6 cm diameter spherical capacitor with dielectric fluid in a 1 cm gap. Radially directed electric polarization forces, produced by applying a voltage and maintaining a temperature differential across the spherical capacitor, create buoyancy forces analogous to those in planetary atmospheres and stellar interiors. The governing equations for the dielectric fluid have the same mathematical form as the Boussinesq approximated equations and by proper selection of applied voltage and temperature differential across the capacitor gap, pole-to-equator temperature differential, and rotation rate the GFFC can be used experimentally to study convection for Rayleigh and Taylor number regimes characteristic of planetary atmospheres. The GFFC experiments must be performed in Earth orbit, because gravity in terrestrial-based laboratories destroys the spherical symmetry of the radial gravitational force field simulated by the electric polarization forces. The GFFC instrument is scheduled to fly on the Spacelab 1 Mission currently planned for May 1983.

The GFFC instrument development was initiated in FY76. During FY80 we will have completed the fabrication and, except for off-gassing tests, all flight qualification testing of the GFFC instrument. The GFFC is scheduled to be completed and accepted by MSFC from the instrument contractor (Aerojet Electrosystems Company, Azusa, California) in July 1980. This event represents a major milestone in the GFFC development program.

Nearly all necessary inputs related to the integration of the GFFC instrument into the Spacelab module have been provided to the Spacelab 3 Mission integration team. This has resulted in the "baselining" of key GFFC/Spacelab 3 Mission interface documentation; namely, the GFFC Experiment Requirements Document and the Instrument Interface Agreement. It is currently planned that 80 hours of GFFC tests will be performed on the Spacelab 3 Mission. Studies related to the effects of spacecraft dynamics on the GFFC instrument have been performed to specify requirements on the attitude and dynamic behavior of the Space Shuttle during GFFC operation.

Current Focus of Research Work:

The work this year on this portion of the GFFC project has been aimed at the successful fabrication, testing, and completion of the GFFC instrument.

Plans for FY81:

The GFFC will be placed in bonded storage at the MSFC and will be removed from time to time for the performance of off-gassing tests (FY81) and operation of the instrument to acquire data on stratified flows. The data associated with the latter will be used for (1) development and test of data processing techniques which will be used for the postflight analysis of the data to be acquired from the Spacelab 3 Mission, (2) check-out of fluid dynamic computational codes, and (3) performance of fundamental studies of fluid dynamic processes in stratified flows, in spherical geometry, in a one-g environment. Item 3 is aimed at assessing the true capabilities of the GFFC and developing familiarity with and facility in the analysis of data from the GFFC to aid in the postflight analysis of the data to be acquired on the SL 3 Mission.

Programming of the GFFC microprocessor experiment parameter memory will take place in FY81 and FY82. This will involve selection of the experiment parameters to be used in the on-orbit tests, specification of experiment duration time, and optimizing the layout of the experiment parameters on the microprocessor memory(programmable read only memory).

Recommendation for New Research:

The GFFC is an extremely versatile instrument which has a wide range of capabilities. It is recommended that studies be performed to explore the potential application of the GFFC to ground-based experiments which have implications relative to the study of geophysical fluid dynamic systems.

**Title:** Overview of the Global Atmospheric Flow Model Experiments for Space Flight Program

**Research Investigators:**

William W. Fowlis
ES82/MSFC, AL 35812

John E. Geisler
University of Miami, Miami, FL 33149

Robert L. Gall
University of Arizona, Tucson, AZ 85721

Basil N. Antar
University of Tennessee Space Inst., Tullahoma, TN

Albert C. Giere
USRA, ES82/MSFC, AL 35812

Jae M. Hyun
NRC, ES82/MSFC, AL 35812

Background:

A major activity of the Geophysical Fluid Dynamics Group at NASA/MSFC is the design and construction of spherical geophysical fluid flow model experiments. A dielectric body force is used to simulate radial gravity. These experiments must be operated in the low gravity environment of an orbiting vehicle because the dielectric force is weak and is overwhelmed by terrestrial gravity in a laboratory on the Earth's surface.

An Atmospheric General Circulation Experiment (AGCE), that will model the large-scale circulation of the Earth's atmosphere, has been proposed for Spacelab flights. In this experiment the working fluid will be contained between two concentric spheres. The pole-equator temperature gradient and the large-scale vertical stability of the atmosphere will be modeled by maintaining latitudinal temperature gradients on the spheres and by maintaining the outer sphere warmer than the inner sphere. The rotation of the Earth will be modeled by co-rotating the spheres.

The major objectives of the AGCE Program are: (1) To realize quasi-geostrophic conditions in the spherical model and to examine the nature of baroclinic instability in the model. (2) To develop a computer code based on the parameters of the AGCE. (3) To resolve the experimental problems of the model and to develop measurement techniques. The scientific problems posed by the AGCE design objectives are mostly unsolved and difficult. The strategy adopted has been to proceed with a hierarchy of theoretical problems of gradually increasing complexity that approximate more and more closely the actual AGCE configuration. This approach should provide the AGCE Program with a sound scientific basis and a good understanding of all the parameters involved.

Significant Accomplishments FY80:

The most important single design criterion for the AGCE is to be sure that the apparatus will exhibit baroclinic instability. Previous stability studies (Fowlis and Fichtl, 1977; Fowlis and Arias, 1978; Geisler and Fowlis, 1979; Antar and Fowlis, 1980) showed that in order to achieve strong baroclinic instability a large value of the dielectric body force is needed. The only practical way to inverse this force is to increase the dielectric constant of the liquid and/or the applied voltage. A feasibility study contract, that will precede the AGCE instrument engineering and fabrication contract, and that will examine the technical problems associated with the required parameter value increases, is now underway.

The dielectric body force varies inversely as the fifth power of the radius. We were concerned that this variation might alter qualitatively the dynamics of baroclinic instability. Previously we tackled a stability problem for variable gravity using a perturbation method (Giere et al, 1980). The problem has now been solved for an inverse linear variation of gravity (Giere and Fowlis; 1980a) and for a general power law variation (Giere and Fowlis, 1980b). The results show that baroclinic instability is insensitive to a variation of gravity, only, the average value is significant.

All of the previous AGCE scientific design work has been pulled together by considering in a numerical model baroclinic instability on a β-plane with an inverse fifth variation of gravity and with Ekman damping. This more sophisticated model gives essentially the same conclusion as the simpler models.

No one has solved analytically a continuous baroclinic stability problem for general variations of the vertical shear and the lapse rate. We have succeeded in solving a two-level model. The results shed light on the effects of these two variations.

A new spherical apparatus for investigation of the experimental and measurement techniques has been constructed. It has been shown that very high voltages do not interfere with the photochromic dye flow measurement technique. The existence of the dielectric body force has been demonstrated. A problem of dust agitation was clarified and resolved.

Plans for FY81:

1. A General Circulation Model and the AGCE Numerical Model

A nonlinear, three-dimensional, numerical model of the AGCE must be constructed if we are to exploit fully the data provided by the Spacelab model. The approach adopted is to simplify the NCAR Spectral GCM. Although the stripped-down GCM will be very similar to the AGCE, it cannot be made identical. Some modifications will be required. The fact that this effort will result in two codes is a substantial asset. A comparison of results will link the AGCE Program to a forefront of GCM research.

2. Rotating Hadley Cells and Their Stability

To improve the design stability calculations more accurate basic states must be determined. The nonlinear, basic state flow for the appropriate boundary conditions in a horizontally infinite rectilinear model will be found and its stability tested.

3. Vertical Boundary Layers in Rotating Fluids

To extend the above Hadley cell studies, we must take into account the vertical motion occurring near the sidewalls or lateral limits We know, in general, that the sidewall layers for models with thermal gradients on their horizontal boundaries are different from the "classical" annulus sidewall layers. We propose a boundary layer analysis for a rectilinar model with a quasi-geostrophic interior.

4. Axisymmetric Flows in Cylindrical and Spherical Geometries

To extend the above work to more realistic geometries, numerical methods are required. We have a suitable, two-dimensional, cylindrical code (Warn-Varnas et al, 1978). We plan to modify this code for spherical geometry.

5. A Spherical, Hydrostatic Model

Although much will be learned from the above tasks, they will not provide quantitative information for the design of the AGCE instrument in a suitable time. To provide such specifications, a numerical, spherical, hydrostatic model will be constructed. This task contains two parts. First, the axisymmetric flow will be computed over appropriate parameter ranges and then the stability will be determined using the linear perturbation technique.

6. Other Theoretical Tasks

Other tasks that are of secondary importance or that have not yet been precisely formulated are being considered. These include analytical studies using spherical, two-level models and some analytical, nonlinear work.

7. Laboratory Development Work

Some further testing of candidate liquids for the AGCE suggested by the feasibility study will be performed using the new spherical development apparatus.

A General purpose rotating turntable and two new cylindrical experimental assemblies will be constructed. This apparatus will be used to compare baroclinic instability in models with heating on horizontal boundaries and lateral boundaries.

Recommendations for New Research:

Future Space Flight Experiments

It is anticipated that the AGCE instrument, with and without modifications, will be used for additional terrestrial, atmospheric flow experiments. An atmospheric blocking experiment in which partial obstructions of the flow will simulate mountain ranges has been suggested.

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Warn-Varnas, A., Fowlis, W. W., Piacsek, S. and Lee, S. M. 1978. J. Fluid Mech., 85, 609.

**Title:** Laboratory Development Work for the Global Atmospheric Flow Models

**Research Investigator:**

William W. Fowlis
ES82/MSFC, AL 35812

**Background:**

The spherical geophysical fluid flow model experiments for space flight contain a relatively small volume of confined liquid. Flow and temperature measurements are required. Clearly, special techniques are needed to make disturbance-free measurements in the liquid. The presence of a large alternating electric field is also a serious complication. A photochromic dye technique (Smith and Hummel, 1973) was suggested for the flow measurement and a Schlieren technique for the temperature measurement. The development work performed on these techniques to make them suitable for the Spacelab geophysical fluid flow experiments is described by Fowlis (1979).

**Significant Accomplishments FY80:**

A larger and more flexible apparatus for the study of the effects of large alternating electric fields on dielectric liquids and photochromic dyes has been constructed. This apparatus consists of two concentric hemispheres mounted on an insulating plate. The inner hemisphere is metallic with an outer radius of 5.00 cm and the outer hemisphere is made of glass with an inner radius of 6.00 cm. An AC voltage (0-20,000 volts rms, 50-1000 Hz) and a temperature difference can both be maintained across the spheres.

Using this apparatus, it was shown that up to about 15,000 volts the electric field does not interfere with the photochromic dye. Also, the existence of the dielectric body force was demonstrated by exciting an internal gravity wave in a stably stratified region by impulsively applying or removing the voltage.

During the above studies it became clear that dust in the oil was excited by the field and seriously agitated the oil. The dust had to be removed. Several techniques were tried. A successful procedure is to pump the oil in a closed circuit from a reservoir through a filter and then through the apparatus. The agitating effect of the dust can also be diminished by increasing the voltage supply frequency.

**Plans for FY81:**

1. Survey for a Suitable Liquid for the Atmospheric General Circulation Experiment (AGCE)

The theoretical scientific design studies for the AGCE have shown that a liquid with a high value of dielectric constant and/or a high voltage is needed. This liquid must also satisfy other requirements; it must have a low dissipation factor, low viscosity, moderate coefficient of expansion, high transparency and high dielectric strength. A compatible photochromic dye must also be found for the flow measurement technique. Although the major remaining technical design problems for the AGCE have been included in the Feasibility Study for investigation by a contractor, our special hemispherical apparatus will still be needed. We shall work in conjunction with the contractor. Once a candidate liquid with a high dielectric constant has been identified and undergone preliminary checks, we shall test it in the spherical apparatus for its behavior in the presence of convection and large alternating electric fields.

The high voltage supplied to the hemispheric apparatus will be increased to 50,000 volts rms over the frequency range 50-1000 Hz.

2. Rotating Cylindrical Apparatuses

We plan to construct a general purpose rotating turntable with fluid and electrical slip ranges. Also, we plan to build two different cylindrical apparatuses for mounting on the turntable. The first of these will be a "classical" differentially heated, cylindrical annulus in which the working fluid is contained between two vertical concentric cylinders and these cylinders are maintained at different temperatures. The second apparatus will be similar except that the flow will be driven by thermal gradients maintained on the horizontal annulus boundaries and the vertical boundaries will be thermal insulators.

With the above two apparatuses it will be possible to examine the differences in the flow for the different heating configurations. Differences are expected. The second apparatus corresponds more closely to the AGCE and the atmosphere where the flow is driven by a latitudinal thermal variation. The baroclinic stability of the flow in the second apparatus will provide valuable information for the AGCE design. Where relevant, measurements of these flows will be used to check the numerical, cylindrical codes.

## References


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**Title:** **Baroclinic Stability Calculations on a β-Plane and Studies with a Spectral General Circulation Model**

**Research Investigator(s) Involved:**

J. E. Geisler
Division of Meteorology & Physical Oceanography
Rosentiel School of Marine & Atmospheric Sciences
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149

Significant Accomplishments FY80:

Background: The traditional means of displaying the characteristic features of geophysical flows in laboratory rotating annulus experiments is the so called regime diagram wherein the ordinate is a thermal Rossby number and the abscissa is a Taylor number. The most basic feature apparent in a regime diagram is a division of the parameter space into two regions: one of axially symmetric motion and one of wave motion. The location of the boundary between these two regions has been explained in theoretical terms by means of the Eady model of baroclinic instability.

Briefly stated, the objective of the Atmospheric General Circulation Experiment (AGCE) is to generate and analyze laboratory geophysical flows in spherical geometry. Theoretical regime diagrams incorporating the effects of spherical geometry are needed both for the design of this experiment and for the interpretation of the results of the experiment. During FY79 we developed a numerical model of baroclinic instability in a β-plane channel and used this model to generate regime diagrams that incorporate the effects of β. The differences between such regime diagrams and those with no β (obtained from the Eady model) were identified and interpreted. In FY 1980 we modified the β-plane channel model to incorporate an inverse fifth power law gravity, the need for such a step being dictated by the fact that the electrostatically-simulated radial gravity field in the AGCE laboratory device is one of inverse fifth power. We used this modified numerical model of baroclinic instability in a β-plane channel to generate new regime diagrams. Our principal conclusion is that for range of parameters that are realistic for the AGCE laboratory device, the regime diagrams with inverse fifth power gravity differ very little from those with conventional (that is, constant) gravity as far as the location of the boundary separating the axially-symmetric and the wave regime is concerned.

## Current Focus of Research Work:

We now propose to generate theoretical regime diagrams using a numerical model that takes full account of spherical geometry. Toward this end, we propose to operate an Atmospheric General Circulation Model (GCM) as an analogue of the AGCE experiment. In using a GCM for this, we have the further advantages (over the $\beta$-plane channel model) that the axially-symmetric component of the flow is generated by the model itself and the dynamics of this and the wave component of the flow are nonlinear. We have selected as the GCM a spectral model recently developed at the National Center for Atmospheric Research (NCAR). Our current focus is on learning the workings of this GCM.

## Plans for FY81:

Our next task is to strip down the GCM until it becomes essentially a device for solving the nonlinear primitive equations on a sphere. This involves deleting from the model such things as the hydrological cycle, radiative heating and cooling, and all topography. We will then operate the model as an analogue of the AGCE experiment, proceeding as follows. First, we initialize the model by specifying the latitudinal distribution of surface temperature and the rotation rate. We then categorize the motion field that develops as axially-symmetric or wavelike (globally are according to latitude bands) and attempt to identify any further distinguishing characteristics. We then initialize the model with a new surface temperature distribution and/or rotation rate and repeat the experiment.

**Title:** A General Solution of the Eady-Type Equation of Baroclinic Instability

**Research Investigator(s) Involved:**

A. C. Giere & W. W. Fowlis
ES82/MSFC 453-3104

**Significant Accomplishments FY80:**

In the spherical Atmospheric Geophysical Cell Experiment (AGCE) for Spacelab, a dielectric body force will simulate terrestrial gravity. This simulated gravity field varies inversely as the fifth power of the distance. Since in the experiment the ratio of the atmospheric thickness to the radius is much smaller than for the corresponding ratio for the Earth, a theoretical investigation was undertaken to determine whether a variable gravity field would affect the essential dynamics of baroclinic instability. It has been found that the effect is small, being more quantitative than qualitative. The theoretical results obtained are also applicable to other geophysical flows in which the vertical temperature gradient varies with height and gravity is constant. The results have been accepted for publication in the Journal of Geophysical and Astrophysical Fluid Dynamics.

A second theoretical investigation, whose results have been submitted for publication to the Journal of Fluid Mechanics, involved the solution of the Eady-type equation of baroclinic instability in which the rotational Froude number is a general power law function of the height. The results obtained include the variable gravity problem as a special case in addition to a four-thirds power law solution first given by Williams in a 1970 paper. Since the rotational Froude number is a function of both gravity and the vertical temperature shear, the results are applicable in the atmosphere, ocean, and the laboratory annulus in which the rotational Froude number varies with height.

Current research is on the non-linear aspects of baroclinic instability. Very little work has been done in this area. The focus will be on the effect of non-linearity on the rather well-known and extensive results of linear theory.

TITLE: REAL HADLEY CELL CIRCULATIONS AND THEIR STABILITY AND THE AGCE NUMERICAL MODEL

RESEARCH INVESTIGATOR: Dr. Basil Antar
The University of Tennessee
Space Institute
Tullahoma, TN 37388
(615) 455-0631

SIGNIFICANT ACCOMPLISHMENTS FY - 80:

1. A paper authored by B. Antar and W. Fowlis on work resulting from FY - 79 funding is to appear in the Journal of The Atmospheric Sciences in June 1980.

2. In order to enlarge upon, and extend our basic understanding of baroclinic stability and also to aid in the analysis and formulation of the design criteria for the AGCE experiment, a model representing real Hadley cell circulations and their stability was formulated and analysed. The model consisted of a layer of fluid confined between two horizontal planes which are seperated a distance D apart. The fluid is assumed to be infinite in the horizontal direction and is subjected to a constant horizontal temperature gradient at the two bounding planes. Also, to insure that the model represents baroclinic instability conditions the upper plane was assumed to be uniformly at a higher temperature than the lower plane.

   The analysis proceeded by first solving the governing equations of this model for the stationary basic state. The solution for the basic state yielded a strong zonal velocity profile which is almost linear, with respect to height, in the interior of the fluid with two Ekman layers next to the bounding planes. The temperature distribution in the fluid was also almost linear in the interior and again with strong thermal layers next to the horizontal boundaries. These solutions for the basic state were obtained in a closed form.

   Next the stability of this basic state was analyzed with respect to infinitesimal, two-dimensional zonal waves. The linear equations governing the perturbation velocity and temperature resulted in an eighth order linear differential eigenvalue system. Due to the complexity of the basic state, the perturbation system was solved numerically. Thus, a computer code was written and run specifically for this system. The solution was established in the form of regime diagrams seperating the stable from the unstable waves. As of this date eigenvalues for this model are still being produced.

3. Contacts were established with NCAR Scientists in order to study and possibly modify the stripped down NCAR GCM model. Background studies have been completed on how best to implement the necessary modifications to the NCAR GCM code in order to bring the numerical model closer to simulating the actual conditions of the AGCE experiment.

CURRENT FOCUS OF RESEARCH WORK:

1. Regime diagrams for the Hadley circulation stability model will be produced and efforts will be made to facilitate comparison between the results of the present model and previous published work on baroclinic instability. Also, the results of the present model will be presented in a format such that it will be of maximum use for the design criteria of the AGCE. If results permitted, a $\beta$-plane effect will be added to the model and stability criteria will be established.

2. All necessary modifications of the stripped NCAR GCM model will be implemented and the resulting code will be verified and run.

PLANS FOR FY - 81:

1. The modified stripped NCAR GCM model will be run for parameters representing those that are called for in the design of AGCE.

**Title:** Separate and Combined Effects of Shear and Stability in Baroclinic Instability

**Research Investigator:** J. M. Hyun,
NRC/MSFC,
ES 82, Marshall Space Flight Center,
Alabama 35812
Telephone Number (205)-453-2047

**Significant Accomplishments FY-80:**

A study is made of the instability characteristics of quasi-geostrophic baroclinic disturbances in a linearized two-layer Eady model, in which both the static stability and the current shear are uniform but different in each layer. The effects of Richardson number variations due to changes in shear are shown to be analogous to the effects of Richardson number variations due to changes in static stability. The instability characteristics, especially at short wavelengths, are found to be profoundly affected by not only the variation of the Richardson number but also the way in which the Richardson number is made up. This suggests that the static stability and the shear are in general two separate parameters in the problem, rather than appearing in combined form through the Richardson number. The relative importance of the static stability and the shear, together with the question of the primary location of the short-wave instability, is clarified by checking the sign of the basic-state potential vorticity gradient present at the layer interface. The effect of the relative layer thickness is also examined, and the results are in general agreement with the two-layer model results given by Blumen (Ref. 1). A two-layer analog is constructed of the continuous model of generalized Eady waves (Ref. 2), taking note of the implications of the vanishing of the potential vorticity gradient in the entire fluid interior. Despite its apparent crudeness, the simple two-layer model seems, within the range of parameters typical of tropospheric conditions, to reproduce the essential features characteristic of the generalized Eady waves successfully. The computed wave structures of unstable waves provide additional support for the applicability of the two-layer set-up in modeling the generalized Eady waves, underscoring the versatility of a two-layer model in obtaining qualitative understanding of the flow phenomena.

References

1. Blumen, W., 1979: J. Atmos. Sci., 36, 1925-1933.
2. Williams, G. P., 1974: J. Fluid Mech., 62, 643-655.

**Current Focus of Research Work:**

**Plans for FY-81:**

**Recommendations for New Research:**

In an effort to better understand the basic states, the model problem of axisymmetric flows in a finite cylinder, driven by the thermal gradients along the horizontal boundaries, will be studied for a small Ekman number. In order to simulate the conditions for AGCE, the vertical temperature difference is assumed to be large, and the side walls are assumed to be insulating. Because of the geometrical constraints, the side wall boundary layers are expected to play a significant role. The numerical code (Ref. 1), which has been used successfully for the homogeneous spin-up problem, is being reviewed and modified for the present problem. Preliminary undertakings appear to be quite promising, and continued efforts will be exercised to upgrade the code, in conjunction with the analytical back-up studies.

References

1. Warn-Varnas, A., Fowlis, W. W., Piascek, S., and Lee, S. M., 1978: J. Fluid Mech., 85, 609-639.

# A Numerical Axisymmetric Spherical Model and Its Stability and Future Experiments

Timothy Miller and Robert Gall
University of Arizona
Tucson, Arizona 85721

Work on this project has just begun, hence, the discussion here will just outline what we intend to accomplish and how. Generally we will attempt to determine when baroclinic waves will be found in the AGCE apparatus for a given set of experimental parameters. To do this, a solution to the axisymmetric primitive equations, as they apply to the AGCE, will be integrated in time to a steady state condition. This, of course, assumes that no eddies will be found in the apparatus. If true, then the solution will be a close approximation to the flow found in the AGCE. If eddies are actually found in the apparatus, then we expect that the axisymmetric solution will be unstable to small perturbations, a condition that can be tested for with a linear model.

The project will therefore consist of two parts. The first will be the development of an axisymmetric numerical model of the fluid contained within the AGCE apparatus. This model will assume that the fluid is incompressible and hydrostatic and will employ numerical procedures similar to those described by Bryan and Cox (1968) for a model of the General Circulation of the ocean. The assumption of incompressibility is excellent for the fluids being considered for AGCE. The hydrostatic assumption, however, may be somewhat crude. We make this assumption to simplify the numerical calculation and therefore reduce consumption of computer time. We don't expect that the hydrostatic assumption will introduce fundamental errors, however, to test this we intend to later include non-hydrostatic effects in the model and redo at least some of the calculations.

Given a certain experimental configuration, (geometry of the apparatus, fluid used, imposed temperature gradients on the boundaries, etc.) the axisymmetric model will be integrated in time until a quasi-steady state is reached (probably defined as the time when the global average temperature becomes slowly varying). If the resulting flow is stable to small perturbations, then it should be a close approximation of the flow that will be found in the AGCE for that particular configuration. If not, the flow must contain baroclinic waves.

In the second part of the project, linear models will be developed to determine whether the flows generated by the axisymmetric model described above are unstable to small perturbations. The stability analysis will be conducted in two steps. First, a numerical model using the linearized quasi-geostrophic equations on a "beta-plane" will be used to at least crudely determine instability of the flows generated by the axisymmetric model. This model will allow full vertical and horizontal variations of the wind field, yet the stability analysis can be reduced to a relatively simple eigenvalue problem. This will provide a quick look at the stability properties of a particular flow but the horizontal and vertical resolution must necessarily be very low. Furthermore, spherical effects will be only approximated.

To allow a high resolution, more complete stability analysis, a numerical model using the linearized primitive equations will be constructed. The model will be incompressible and hydrostatic (the hydrostatic assumption should be good for the linear calculations) and will use numerical procedures similar to those used by Blakeslee and Gall (1978).

This primitive equation linear model will take the flow generated by the axisymmetric model and then, for a given wavenumber in the zonal direction, integrate the equations in time until exponential growth of the wave is achieved. The growth rate of the wave at that time defines the instability of that particular wavenumber. The procedure will have to be repeated for other wavenumbers to define a growth rate spectrum. If the wave is actually stable, then no growth of the wave will be observed.

With these two sets of numerical models we should be able to determine whether a given experimental configuration will contain baroclinic waves or not. We assume that if the flow is unstable, then waves should be present. By examining a number of experimental configurations we can determine which will produce baroclinic waves.

To test whether this method can indeed determine where baroclinic waves will be found in the AGCE apparatus, the same procedure will be applied to a rotating annulus experiment for which a stability diagram has been experimentally determined. If our numerical procedures can produce such a diagram for the annulus, then we feel that they should be able to produce a similar diagram for the sphere.

## References


Bryan, K. and M. Cox, 1968: "A Nonlinear Model of an Ocean Driven by Wind and Differential Heating: Part I. Description of the Three-Dimensional Velocity and Density Fields." J. Atmos. Sci., 25, 945-967.

Blakeslee, R. and R. Gall, 1978: "The Effect of the Meridional Circulation on the Baroclinic Instability of the Winter Zonal Flow." J. Atmos. Sci., 35, 2368-2372.

## UTILIZATION OF SATELLITE DATA AND DYNAMIC PRINCIPLES IN UNDERSTANDING GLOBAL WEATHER PHENOMENA

John H. E. Clark (814-863-1581) and John A. Dutton (814-865-1534)
The Pennsylvania State University, Walker Building, University Park, PA 16802

The basic hypothesis of our research is that the combination of global satellite data with the increasing knowledge about multiple solutions of nonlinear hydrodynamic equations offers possibilities for achieving an improved understanding of the evolution of weather patterns and an enhanced capability for prediction of global weather phenomena. For both weather prediction and understanding of climate variability, we need to know where the present atmospheric regime lies in the hierarchy of possible solutions.

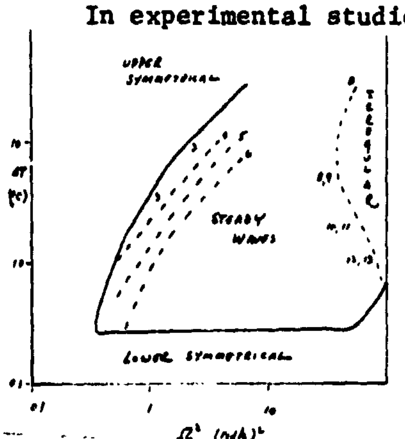

Fig. 1 (from Fowlis and Hide)

In experimental studies of convection, the sequence of events is that, as the Rayleigh number increases, the flow changes from a steady, conductive regime to steady convection, then to periodic motions in three dimensions, then to patterns with more than one period, and finally to turbulence. In rotating annulus experiments, quite a different pattern has been observed (Fig. 1, adapted from Fowlis and Hide), with a wave regime embedded in a region in parameter space in which the symmetric response of the Hadley regime is prevalent. As is evident, rotation appears more important than heating in determining which wave patterns will dominate.

The essence of our task is to determine the critical variables or patterns that herald the sudden transitions between flow types and then to develop methods of using satellite data to monitor these critical parameters.

### Progress, Present Efforts, and Future Plans

1. Studies of Moist Convection and Cloud Development

We are attempting to compare the properties of solutions to low-order truncated spectral models of moist convection with the properties of shallow convective cloud patterns as revealed by satellite imagery.

Studies completed and published or in press have involved spectral models that portray only a limited number of nonlinear interactions. Still, a surprising number of different solutions can occur. H. N. Shirer investigated the multiple solutions of a convective flow superimposed on a vertically shearing current and was able to predict the angle between the cloud bands and the basic flow as well as the propagation velocity of the cloud bands.

In future work we will turn our efforts toward development of a spectral model in which there are sufficient degrees of freedom for two orthogonal, two-dimensional rolls and a three dimensional cellular state. In addition, we will be working with the Meteorologisches Institut, University of Hamburg, on the planning and execution of a major convection experiment over the North Sea in 1981 that will be aimed at theoretical and practical theoretical questions. The results will be significant in relating theoretical results and observed patterns of evolution.

## 2. Studies of Global Response Patterns, the Index Cycle, and Blocking

We are investigating three main questions:

i) Does the response diagram for the atmosphere resemble Fig. 1, and where is the present regime located on that diagram?

ii) Can our theoretical and numerical results predict and interpret the experimental results to be obtained in the Geophysical Flow Experiment and the Spherical Convection Experiment?

iii) Are the index cycle and the blocking phenomenon evidence of oscillations internal to a particular solution or are they evidence of oscillations between two different solutions?

Our major effort to date on the first two questions is study of the analytical and numerical properties of a large ( 50 coefficients) spectral model of the Hadley regime (H. Henderson). The model is stable to two-dimensional disturbances over a wide range of external parameters; we are now planning to introduce three-dimensional disturbances. With a low-order quasigeostrophic spectral model we have shown that steady waves will transition to nonlinear, periodic flows when zonally dependent heating is intensified (Mitchell and Dutton). We are now looking more carefully at these transitions with a quasigeostrophic spectral model that is restricted to baroclinic interactions (Clark).

The presence of the five- or six-day cycle associated with traveling cyclones and the period of some 15 to 30 days associated with the oscillation in intensity of the westerlies (known as the index cycle) raises a significant question: Is this behavior a consequence of oscillation between two solutions with distinct periods or is it a manifestation of a solution that has two periods? The answer to this question has important implications for planning the use of the remotely-sensed data for global weather prediction.

A study in progress (S. Feldstein) of spectral properties of 500 mb height and thermal fields is aimed at precise determination of the periods involved in the index cycle.

We are developing a spectral model (Dutton, Clark, Shirer) from a set of primitive equations that will include both the axisymmetric regime and the quasigeostrophic wave regime as special cases. The interaction between regimes as well as interactions within regimes will be accessible to analysis and simulation. We hope to produce an atmospheric equivalent of Fig. 1 and to determine which parameters control the periods and transitions discussed above.

The existence of these two periods suggests that the flow is confined to a small region in phase space. Two structures are possible: i) For a flow with two periods, the classical topological prototype is a solution confined to a torus in phase space; ii) For a flow oscillating between solutions with a shorter and a longer period, the prototype has trajectories in phase space circling around and between two or more unstable fixed points.

Determining which of these is the correct view and determining the topological structure of the resulting attractor or invariant set might make it possible to concentrate our efforts at weather prediction in a quite small domain of phase space. In particular, presentation of satellite data as time-dependent Fourier coefficients (of spatial patterns) in phase space might have significant advantages in understanding and predicting the evolution of global weather patterns.

## THE EFFECT OF LATENT HEAT RELEASE ON GLOBAL WEATHER SYSTEMS

INVESTIGATORS: John H. E. Clark, Penn State University
Telephone: 814-863-1581
George Fichtl, NASA Marshall Space Flight Center
Telephone: 205-453-0875

We plan a theoretical and diagnostic study of the effect of latent heat release on the structure, evolution, and energetics of mid-latitude cyclones. As much as possible, we shall use satellite information to supplement conventional data in our diagnoses.

In many extratropical systems the dominant mode of latent heat release is convention associated with, for instance, cold fronts and squall lines. In the initial stages of this study we shall concentrate on heating associated with the slow uplift in the ageostrophic circulation driven by the constraint on the horizontal winds that they be almost geostrophic, i.e., quasi-geostrophic equations will be used. Later we shall relax this constraint by using the semi-geostrophic equations of Hoskins (1975).

### THEORETICAL ANALYSIS

A great deal of knowledge about extra-tropical systems has been gained through the study of the evolution of infinitesimal waves superimposed on arbitrary east-west currents and their associated north-south temperature gradients. A few studies have attempted to ascertain the effect of latent heating on these waves and the effect seems to be small, Gall (1976), at least while the wave is still in the linear regime. The questions that we plan to answer are the following:

1) What are the effects of latent heating on a growing baroclinically unstable wave as it gets into the non-linear regime? We shall use highly truncated spectral models both quasi and semi-geostrophic to answer this question. The methodology for analyzing the spectral equations for stationary and periodic solutions has been laid out by Lorenz (1963) and Vickroy and Dutton (1979). Later we shall analyze the effect of latent heating on unstable waves in a hydrostatic primitive equation model where horizontally propagating internal gravity waves are allowed.
2) What are the effects of direct in situ latent heating versus extra-cloud indirect heating via induced subsidence? The diabatic heating due to a parcel rising at a rate w can be shown to be

$$\dot{Q} = \frac{c_p \Gamma_d (\Gamma - \Gamma_w)}{\Gamma_w} w \quad ,$$

where $c_p$ is the specific heat. $\Gamma$ is the lapse rate, and $\Gamma_d$ and $\Gamma_w$ the dry and moist lapse rates respectively. In a cloud where the lapse rate is moist adiabatic the local heating is zero but there could be considerable indirect heating due to induced subsidence outside the cloud. We plan to take a detailed look at various combinations of direct and indirect heating on the evolution of baroclinic waves.

and 3) What are the consequences of latent heat release on the energetics of cyclonic disturbances? In particular does the latent heat release enhance the ability of a growing wave to extract energy from the

### DIAGNOSTIC ANALYSIS

Satellite images of cloud patterns associated with extra-tropical cyclones reveal vaste areas of cloud associated with the slow uplift of moisture-laden air. We plan to carry out a detailed analysis of the effects of the latent heat release by, first of all, calculating the vertical motion field and secondly the energy cycle of a few systems. This work should complement that of the Extratropical Cyclone Project and we hope to work with some of the same cases that will be used in that project.

We shall initially assume that the heating is not fast enough to upset the near geostrophic balance of the horizontal wind field and evaluate the vertical motion field from the quasi-geostrophic $\omega$ equation. Some details of our proposed technique are:

1) forcing by horizontal heat and vorticity advections will be evaluated according to the suggestion of Hoskins et al. (1978) by calculating fields of $\vec{\nabla}Q$, where Q is $\vec{\nabla}V_g \cdot \nabla\theta$. The advantage of this technique is that it circumvents problems due to the tendency of the vorticity and heat flux contributions to compensate each other.

2) forcing by condensation within the clouds and/or evaporation from the rainfall below the clouds will be evaluated by a complicated iterative technique involving the use of observed precipitation patterns, satellite observations of the cloud pattern, and radiosonde observations of profiles of mixing ratios both in the cloud decks and below them. The iterative nature of the technique arises because initial guesses for the field of vertical motion are needed to find the latent heating and the criterion for convergence will be agreement between the calculated and observed precipitation patterns. We also plan to develop a variational method to evaluate the latent heating effect eventually.

3) the equations will be solved on a multi-level grid that encompasses the storm. Vertical motions on the lateral boundaries will be obtained from NMC analyses. The lower boundary condition will be set according to the orographically-induced vertical motion fields due to the observed horizontal motion field. A sponge layer will be imposed above 100 mb.

Once the vertical motion fields are found, a detailed analysis of the energy cycle and all the energy transformations will be carried out. In probably the second or third years of this project we plan to attempt an assessment of the effects of convective heat release on the overall energy budget of some storms. This will involve the use of some parameterization scheme since our grid will be much too coarse to explicitly represent the meso-scale features of fronts and squall lines where most of this type of heat release occurs.

In regions where the local vertical component of vorticity is comparable with the Coriolis parameter, the quasi-geostrophic approximation fails. We plan to attempt a diagnosis of these systems with the semi-geostrophic equations of Hoskins (1975). For adiabatic flows, Hoskins shows that these equations can be transformed such that a vertical velocity equation very similar to the quasi-geostrophic $\omega$-equation can be derived. Unfortunately with latent heating present such a convenient transformation is no longer possible. We shall devote a great deal of effort to incorporating diabatic effects into the semi-geostrophic formalism.

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Lorenz, E. N., 1963: Deterministic Non-periodic Flow, J. Atmos. Sci., 20, 130 141.

**Title:** Lower Atmosphere Research From Space: Exploratory Study Progress Report

**Research Investigator:** M. H. Davis
USRA/Boulder

**Preliminary exploration of the concept of a Lower Atmosphere Research Satellite system (LARS)**

**Troposphere, lower Stratosphere**

1. Study Strategy:
   A. What are highest priority research topics?
   B. Which can be investigated using space technology?
   C. Which are already covered by:
      1. Existing data
      2. Experiments already planned
      3. Operational systems, flying or planned
   D. What is left?

Note report by National Academy of Sciences, Committee on Atmospheric Sciences, Chairman C. E. Leith, Jr.: "The Atmospheric Sciences: National Objectives For The 1980's" (in press)

2. Task Groups and Leaders -- National Academy of Sciences Study:

| | | |
|---|---|---|
| A. | Impacts of Weather and Climate on Society | R. G. Fleagle, U. of Wash. |
| B. | Short range forecasting and services | V. E. Suomi, U. of Wis. |
| C. | Mesoscale and synoptic scale forecasts | C. E. Leith, Jr., NCAR |
| D. | Seasonal and interannual climate predictions | J. M. Wallace, U. of Wash. |
| E. | Long range climate change | A. P. Ingersoll, Cal Tech. |
| F. | Advertent weather modification | C. L. Hosler, Jr., Penn St |
| Ga. | Inadvertent weather and climate modification | G. E. Robinson, Cntr.Env.& Mn. |
| Gb. | Atmospheric chemistry | P. J. Crutzen, NCAR |
| H. | Cloud physics | G. B. Foote, NCAR |
| I. | Atmospheric dynamics | J. R. Holton, U. of Wash. |
| J. | Boundary Layer Processes | J. C. Wyngaard, NCAR |
| K. | Atmospheric radiation | J. Weinman, U. of Wis. |
| L. | Solar influence on the earth's atmosphere | J. A. Eddy, NCAR/HAO |

3. Research Areas of Highest Priority:
   A. Weather prediction
      1. Local short-range -- severe weather
      2. Precipitation -- understand, predict
      3. Mesoscale
   B. Climate
      1. Seasonal predictions
      2. Stable weather patterns
   C. Human impacts
      1. Climate effects -- $CO_2$, deforestation
      2. Pollution -- acid rain

4. **Analysis Scheme -- Staircase:**

**Broad Research Area**
(Pollution)
0
0
(Precipitation)

Research Issues
(Warm Cloud Droplet Growth)
0
(Cloud Glaciation)

Research Topics
(Physics of Natural Ice Nuclei)
0
0
(Seeding by Overlying Cirrus)

Research Questions
(Ice Crystal Aggregation)

Specific Problems
(Evaporation of Falling Crystals)
0

(Cirrus Characteristics)

Specific Problems
(Census of Cirrus Occurence)
0
0
0
(Determination of Size, Shape, and Number Density of Ice Crystals)

Methods for Solving Problems
(Aircraft Penetration)
0
0
(Remote Sensing)

Instrumentation--Type
(Ground Based LIDAR)
0
(Passive Radiation Measurements From Satellite)

Planning--Analysis
0
(Radiative Transfer Through Ice clouds)

Is Data Available From Other Sources?

Already in data archives?
Useable?

Available From Other Programs
Operational
Research

Evaluation of Experiment Type
(Can needed data be obtained in this way? Physical limitations)
(Is this the best way to obtain data needed?)

Specific Experiment Plans
(State of instrument development)
(Spacecraft parameters -- orbit, duration, data requirements)
(Weight, power, common use of instruments)

Ground Truth Verification

TITLE: SOLAR-TERRESTRIAL ATMOSPHERE STUDIES

INVESTIGATOR: DR. SHI WU
DEPARTMENT OF MECHANICAL ENGINEERING
UNIVERSITY OF ALABAMA - HUNTSVILLE
P. O. BOX 1247
HUNTSVILLE, ALABAMA 35807
(205) 895-6154

## SYNOPSIS OF STUDIES - I

PURPOSE: TO EVALUATE CHAINS OF MECHANISMS HYPOTHESIZED TO CONNECT SUN'S BEHAVIOR TO THAT OF EARTH'S LOWER ATMOSPHERE

GROUND RULES: NOT A REVIEW OF STATISTICAL CORRELATION STUDIES

FINDING THAT A PROCESS CAN NOT BE SIGNIFICANT IS AS IMPORTANT AS IDENTIFYING A PROCESS THAT MIGHT BE SIGNIFICANT

EXTENSION OF A CAUSAL CHAIN AROUND A KEY LINK IS IMPORTANT OUTPUT

## SYNOPSIS OF STUDIES - II

ORGANIZATION:

SOLAR BEHAVIOR - A. S. KRIEGER - A. S. & E.

CHAINS IN WHICH ELECTRICAL BEHAVIOR IS KEY LINK - ARTHUR A. FEW - RICE

CHAINS RELATED TO SPECIFIC METEOROLOGICAL PHENOMENA - M. H. (BILL) DAVIS - USRA, BOULDER

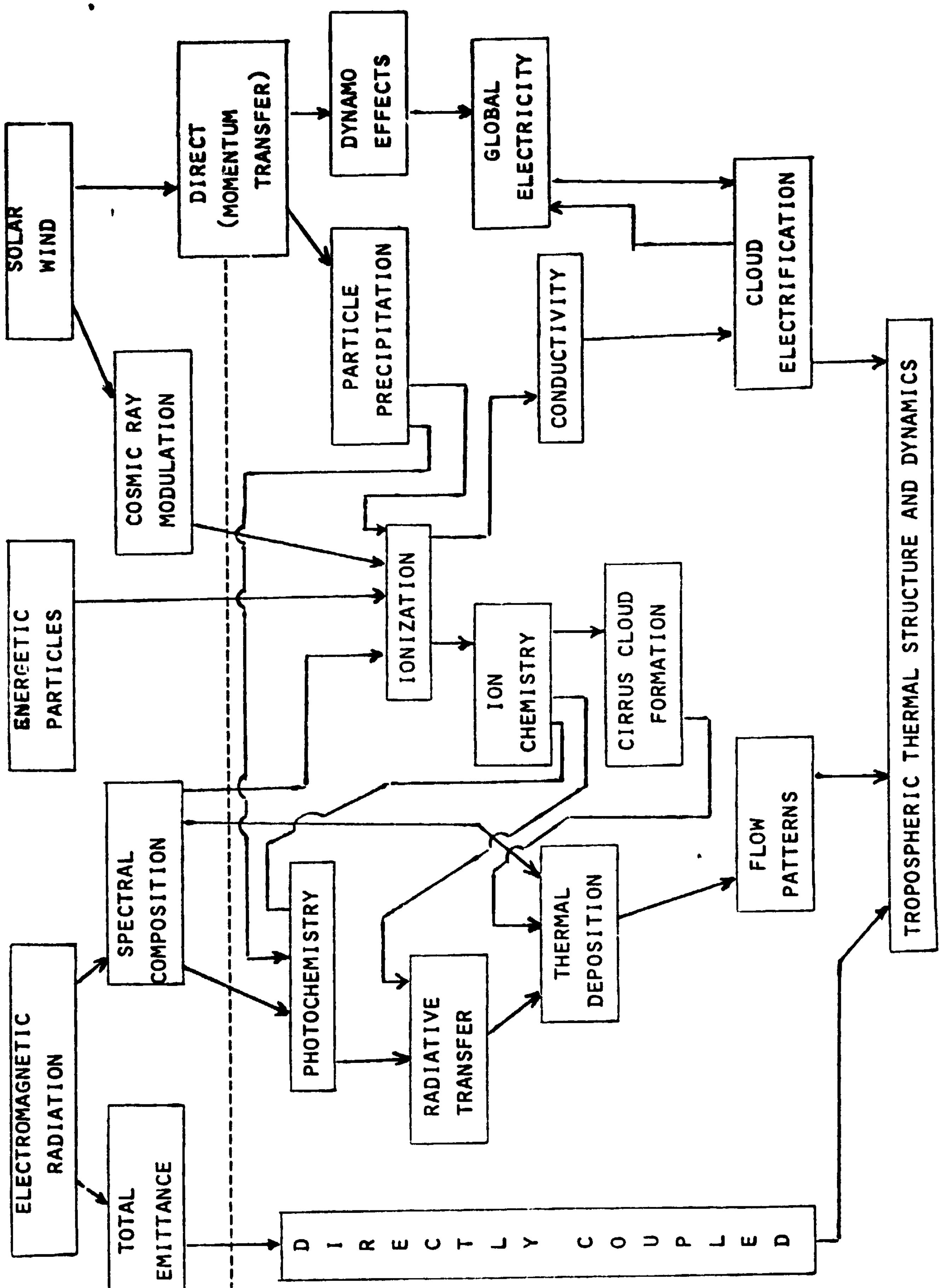
CRITICAL REVIEW ACTIVITIES - S. T. WU - UAH

RESULTS: DID NOT IDENTIFY ANY ONE "MOST PROBABLE CHAIN"

IDENTIFIED SOME PROCESSES THAT MUST BE CLASSED AS "HIGHLY IMPROBABLE"

IDENTIFIED SOME PROCESSES THAT MAY BE CRITICAL

PINPOINTED SOME AREAS FOR FUTURE RESEARCH



SOLAR WIND
DIRECT (MOMENTUM TRANSFER)
DYNAMO EFFECTS
GLOBAL ELECTRICITY
PARTICLE PRECIPITATION
CONDUCTIVITY
CLOUD ELECTRIFICATION
COSMIC RAY MODULATION
ENERGETIC PARTICLES
IONIZATION
ION CHEMISTRY
CIRRUS CLOUD FORMATION
FLOW PATTERNS
TROPOSPHERIC THERMAL STRUCTURE AND DYNAMICS
ELECTROMAGNETIC RADIATION
SPECTRAL COMPOSITION
PHOTOCHEMISTRY
RADIATIVE TRANSFER
THERMAL DEPOSITION
TOTAL EMITTANCE
D I R E C T L Y   C O U P L E D

## CHAINS INVOLVING ELECTRICAL PARAMETERS AS KEY LINKS

ELECTRICAL PRESSURE:

1. $P_E \leq 10^{-12}\ P_A$ IN CLEAR AIR TROPOSPHERE = NO
2. $P_E \leq 10^{-6}\ P_A$ IN THUNDERCLOUD = MAYBE IN EQUATORIAL CASE
3. $P_E \simeq P_A$ IN THERMOSPHERE = PROBABLY NO

ION CHEMISTRY CONNECTIONS:

1. ION PRODUCTION RATES ] = MAYBE
2. ELECTRIC FIELD DRIFT OF IONS ] = MAYBE
3. ION CLUSTER - I R RADIATION = NO

AEROSOL AND PARTICULATE SCALE:

1. ION INDUCED NUCLEATIONS = PROBABLY NO
2. ION ASSISTED GAS TO PARTICLE CONVERSIONS = MORE WEAKLY PROBABLY NO

   (THEORETICAL AVERAGE MOBILITY $1.75\ cm^2V^{-1}S^{-1}$
   WHILE MEASURED AVERAGE MOBILITY $1.2\ cm^{-2}V^{-1}S^{-1}$
   AVERAGE LIFETIME FOR SOME IONIC SPECIES LONG)
3. ELECTRIC-FIELD-ASSISTED COALESCENCE = MAYBE
   (MECHANISM NOT WELL RESEARCHED)

# CHAINS INVOLVING ELECTRICAL PARAMETERS AS KEY LINKS

HIGH ALTITUDE CLOUDS

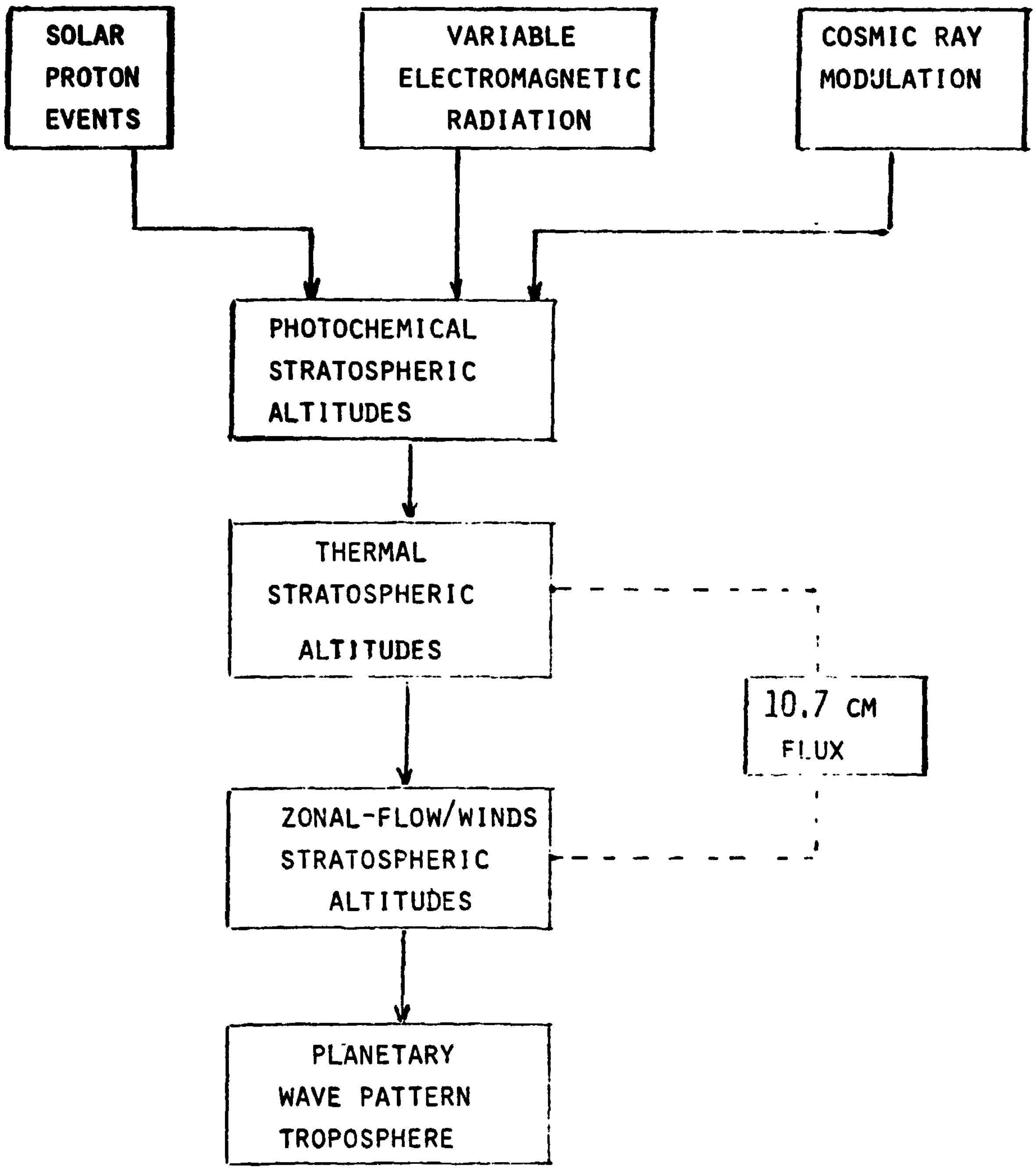
1. ELECTRIC-FIELD-ASSISTED COALESCENCE - AS BEFORE
2. "VENETIAN BLIND" EFFECT - PROBABLY NOT EFFECTIVE

CONVECTIVE CLOUDS

1. CONVECTIVE CHARGING -
   A. STRUCTURE OF FAIR WEATHER FIELD DETERMINES WHETHER INTENSE ELECTIFICATION OCCURS
   B. CONDUCTIVITY ABOVE CLOUD COULD CONTROL RATE. (MECHANISM NOT PROVEN)
2. INDUCTIVE CHARGING -
   A. STRENGTH OF FAIR WEATHER FIELD INFLUENCES RATE(S) IN EARLY STAGES
      (CHUI/ORVILLE MODEL PREDICTS INFLUENCE ON FINAL FIELD STRENGTH IN CLOUD)
3. ELECTRICAL LOAD VARIATIONS -

   CONDUCTIVITY CHANGE ABOVE CLOUD TOPS

GLOBAL CIRCUIT:


SOLAR PROTON EVENTS
VARIABLE ELECTROMAGNETIC RADIATION
COSMIC RAY MODULATION
PHOTOCHEMICAL STRATOSPHERIC ALTITUDES
THERMAL STRATOSPHERIC ALTITUDES
10.7 CM FLUX
ZONAL-FLOW/WINDS STRATOSPHERIC ALTITUDES
PLANETARY WAVE PATTERN TROPOSPHERE

# SECTION II. UPPER ATMOSPHERIC RESEARCH

The NASA program of Upper Atmospheric Research, developed under the Congressional mandates in the FY 1976 NASA Authorization Act and the Clean Air Act Amendments of 1977, is a comprehensive program of research, technology and monitoring. It is aimed at expanding the scientific understanding of the earth's stratosphere and mesosphere and at developing the ability to assess potential threats to the upper atmosphere.

Shelby Tilford

**TITLE: ATMOSPHERIC EMISSIONS PHOTOMETRIC IMAGER ON SPACELAB**

**RESEARCH INVESTIGATORS:**

Spacelab 1


| | |
|---|---|
| Dr. S. B. Mende - Principal Investigator | (415) 493-4411, Ext. 5786 |
| Lockheed Palo Alto Research Laboratory | |
| Palo Alto, CA 94304 | |
| | |
| Dr. R. H. Eather - Co-Investigator | (617) 969-0100 |
| Department of Physics, Boston College | |
| Chestnut Hill, MA 02167 | |
| | |
| K. S. Clifton - Co-Investigator | (205) 453-2046 |
| B. J. Duncan - Co-Investigator | (205) 453-0109 |
| Dr. R. J. Naumann - Co-Investigator | (205) 453-0904 |
| Dr. D. L. Reasoner - Co-Investigator | (205) 453-3037 |
| Dr. G. R. Swenson - Co-Investigator | (205) 453-3040 |
| Space Sciences Laboratory | |
| NASA/Marshall Space Flight Center, AL 35812 | |


Future Spacelab


| | |
|---|---|
| Dr. S. B. Mende - Principal Investigator | (415) 493-4411, Ext. 5786 |
| Dr. W. G. Sandie, Co-Investigator | (415) 493-4411, Ext. 5638 |
| Lockheed Palo Alto Research Laboratory | |
| Palo Alto, CA 94304 | |
| | |
| Dr. R. H. Eather, Co-Investigator | (617) 969-0100, Ext. 3595 |
| Physics Department, Boston College | |
| Chestnut Hill, MA 02167 | |
| | |
| Dr. G. R. Swenson, Co-Investigator | (205) 453-3040 |
| K. S. Clifton, Co-Investigator | (205) 453-2305 |
| Space Sciences Laboratory | |
| NASA/Marshall Space Flight Center, AL 35812 | |
| | |
| Dr. P. M. Banks, Co-Investigator | (801) 752-4100, Ext. 7761 |
| Physics Department | |
| Utah State University | |
| Logan, Utah 84322 | |
| | |
| Dr. M. Mendillo | (617) 353-2-40 |
| Department of Astronomy, Boston University | |
| Boston, MA 02215 | |
| | |
| Dr. R. Orville | (518) 457-3935 |
| Department of Atmospheric Science | |
| The University of Albany | |
| Albany, NY 12222 | |
| | |
| Dr. John Meaburn | |
| Department of Astronomy, University of Manchester | |
| M139PL ENGLAND | |

SIGNIFICANT ACCOMPLISHMENTS FY-80:

The Imager was proposed and accepted as a Spacelab 1 experiment. Several experiments have been proposed for future missions and those have been accepted for definition. The Imager as configured for Spacelab 1 has two optical channels. The TV channel has a selectable $6^{0}$ or $20^{0}$ FOV and uses an image intensifier in series with an SEC vidicon television tube. This channel is sequenced by a dedicated computer so sensitivity and signal to noise can be optimized for the scientific objectives. The second channel includes a 10 x 10 m-channel photon counting array which is bore sighted with the higher resolution TV. The instrument includes its own pointing system and experiment developed software for optimum experiment control. The responsible institutions include LMSC for the optical system and MSFC for the pointing system, computer, software, and environmental test.

Flight hardware and software is approaching the end of the manufacturing and assembly stages and some of the environmental testing on the flight hardware should be completed by the end of the fiscal year.

Flight and ground operational sequences for flight checkout and functional objectives have been defined and conveyed to the Spacelab flight crew and ground operations personnel.

S. Mende and G. Swenson participated in a rocket experiment payload, assembled by J. Winkler (University of Minnesota) and colleagues, which included a large electron accelerator. The payload was launched from Poker Flat, Alaska, and produced five minutes worth of artificial aurora. Ground based low light level cameras up-range observed the phenomena. The ground experiment produced valuable experience and data for several Spacelab 1 experimental objectives.

The prototype m-channel plate photon counting array (PCA) produced significant pixel crosstalk. This crosstalk was eliminated by placing the anodes closer to the micro channel plate chevron in the flight version of the detector. The "crosstalk" can be used to improve optical resolution (see proposed research).

CURRENT FOCUS:

1. To continue with an active ground experiment program using like systems to understand atmospheric and magnetospheric processes. Observation of chemical releases from "Firewheel" experiment and nightglows are planned.

2. To complete the experiment hardware/software assembly and test.

3. To begin definition of reflight configuration so that scientific return of proposed reflight objectives can be achieved.

**PLANS FOR FY-81:**

1. Continue with 1 - 3 above.

2. To evolve "crosstalk" array toward a high resolution, photon counting limited imager of atmospheric emissions.

TITLE: HIGH RESOLUTION DOPPLER IMAGER (HRDI) ON SPACELAB.

RESEARCH INVESTIGATORS:

Professor Paul B. Hays, Principal Investigator
Professor of Atmospheric and Oceanic Science
Space Physics Research Laboratory
University of Michigan
Ann Arbor, Michigan 48109
(313) 764-7220

Co-Investigators:

Professor M. A. Biondi
Professor of Physics
Physics Astronomy Department
University of Pittsburgh
Pittsburgh, Pennsylvania 15260
(412) 624-4354

Dr. Gonzalo Hernandez
Physicist
NOAA/Aeronomy Laboratory
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303
(303) 499-1000, Ext. 3571

Dr. Gary R. Swenson
Space Scientist
ES53
NASA/Marshall Space Flight Center, Alabama 35812
(205) 453-3040

Dr. David Rees
Lecturer in Physics
Physics and Astronomy Department
University College London
Gower Street,
London WCIE 6BT, ENGLAND
QI-387-7050, Ext. 396

Dr. Douglas G. Torr
Associate Research Scientist
Space Physics Research Laboratory
University of Michigan
Ann Arbor, Michigan 48109
(313) 764-7220

Dr. Gordon G. Shepherd
Professor Physics
Associate Director, Center for Reserach in Experimental Space Science
York University
Toronto, Ontario, Canada MdJ IT3
(416) 667-3221

SIGNIFICANT ACCOMPLISHMENTS FY-80:

As an introduction, this study entails the definition of an experiment for future Spacelab missions. The proposed instrumentation includes a large aperture Fabry-Perot interferometer articulated on its dedicated pointing platform. The scientific experiments include measurements and studies of stratospheric and mesospheric dynamics, thermodynamics, and compositions. These studies include dayside and nightside measurements of natural and scattered or resonant emissions of atmospheric molecules.

Definition activities have not begun as of this writing.

CURRENT FOCUS OF RESEARCH WORK: N/A

PLANS FOR FY-81:

Hardware definition activity should continue through FY-81.

RECOMMENDATIONS FOR NEW RESEARCH: N/A

# SECTION III. SEVERE STORMS AND LOCAL WEATHER RESEARCH

The NASA program of Severe Storms and Local Weather Research is to conduct applied research and development using space-related techniques and observations that will increase the basic understanding of storms and local weather which will help to improve the accuracy and timeliness of local weather forecasts and severe weather warnings.

James Dodge

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# A. MESOSCALE/SEVERE STORMS

**Title**: **Enhanced Convection-Initiated Gravity Waves and Tornado Detection from Ionosphere and GOES IR Digital Data Analysis**

**Research Investigators:**

R. J. Hung, The University of Alabama in Huntsville
Huntsville, Alabama 35899
Telephone: (205) 895-6077
R. E. Smith, Space Sciences Laboratory
NASA/Marshall Space Flight Center, Alabama 35812
Telephone: (205) 453-3101
G. S. West, Space Sciences Laboratory
NASA/Marshall Space Flight Center, Alabama 35812
Telephone: (205) 453-1557

**Significant Accomplishments FY-80:**

Ionospheric Doppler sounder observations of gravity waves associated with tornadic storms on August 5, 1975 (touchdown location in south central Louisiana); on January 25, 1976 (touchdown locations in west central Louisiana and in southwestern Mississippi); on March 24, 1976 (touchdown location in south central Louisiana); and on April 11, 1976 (touchdown locations in southeastern Arkansas and southwestern Tennessee) were investigated. Ray tracing computation of gravity waves detected on the Doppler sounder records were carried out to identify the locations of the wave sources. These results all show that the sources of the gravity waves were severe thunder clouds with enhanced convection where tornadoes touch-downed more than one hour after the gravity waves were excited.

Gravity waves associated with Hurricane Frederic on September 12, 1979 were also studied. Comparison of the computed probable sources of the gravity waves and the track of Hurricane Frederic showed that the locations of the computed wave sources were more than three hours ahead of the storm. About 100 km south of the Alabama coast line the track of the sources of the waves made an abrupt left turn. More than three hours later the storm itself made the same left turn. If this occurrence can be verified by analyses of additional hurricane data perhaps this important characteristic can be utilized in forecasting hurricane tracks.

A study was made of the GOES IR digital data during the time period between when the gravity waves observed by the Huntsville Doppler array were being excited and the touchdown of the Oklahoma tornado of May 29, 1977. The analysis shows that the clouds associated with this tornado were characterized by both a very low temperature at the cloud top and a very high growth rate of the cold region of the cloud top, the signature of enhanced convection in the cloud. Comparison between the gravity wave observations and GOES IR digital data shows that the gravity waves were excited when the cold region or high-altitude portion of the cloud top was growing rapidly. The data available for this single case, both from the Doppler array and the satellite, show that there is more than one hour lead time on the touchdown of the tornado. This analysis also shows that the lower temperature region, higher altitude portion, of the cloud elements collapsed before the touchdown of the tornado. This result is in good agreement with the aircraft observations of overshooting tops discussed by Fujita.

These results are based on the case study of GOES IR data on May 29, 1977. Needless to say further studies are required with different data sets before more definite conclusions can be reached.

Current Focus of Research Work:

Results of the analysis of the 29 May 1977 Oklahoma storm analysis show that the gravity waves were excited when the cold region of the cloud top was expanding rapidly. It also again shows that there is a lead time of more than one hour between the excitation of the waves and the touchdown of the tornado. Further comparisons of GOES IR digital temperature distribution data and rates of change of temperature of the cloud top with Doppler gravity wave data are urgently needed to confirm these preliminary results.

Our current focus is to analyze the GOES IR digital data and the Doppler gravity waves data associated with the tornadoes on August 5, 1975; January 25, 1976; March 24, 1976; and April 11, 1976. We have requested the GOES IR digital data for the above time periods; however, to date we have not received any single complete set of data.

Plans for FY-81:

Continuation of the investigation of characteristics of gravity waves associated with tornadoes, the study of wave generation mechanisms, and the conditions for tornado initiation from GOES IR digital data and data from Doppler records is planned.

In particular, we are going to analyze cloud top temperature distributions and rates of change of temperature on those days for which we have completed the analysis of the Doppler gravity waves. Furthermore, we also plan to broaden our analysis of the gravity wave generation mechanisms in Hurricane Frederic. This comparison of Doppler array data and satellite IR data could lead to the discovery of the gravity wave triggering mechanisms, a necessary requirement for developing an early warning system.

Recommendations for New Research:

Our preliminary results show that the combination of satellite IR digital data and Doppler array data is a powerful tool for investigating severe storms. Extension of the current analysis techniques using the data from our updated data gathering system in combination with rapid scan satellite IR digital data should provide us with even more insight into possible tornado initiating conditions and mechanisms.

**Acoustic and gravity waves in the neutral atmosphere and the ionosphere, generated by severe storms.**

Research investigator - Nambath K. Balachandran
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, N. Y. 10964
Phone: 914 359-2900 x 355

Significant accomplishments during FY-80 include the completion of a paper on a case study of gravity waves from thunderstorms. The study showed that severe thunderstorms generated gravity waves which in turn triggered new thunderstorms as they propagated when proper conditions of temperature and humidity existed. The gravity waves travelled long distances under the influence of a duct associated with a critical level.

The array of ionospheric Doppler system has been assembled. Two of the transmitters are already operating. Acoustic signal from the eruption of Mount St. Helena volcano has been recorded on our ground-level pressure sensors. A rough computation showed that the energy release in the volcanic eruption is the equivalent of 10-15 tons of TNT.

A receiver to detect beacon satellite transmissions has been installed. By studying the Faraday rotation of the transmission, the total electron content and its perturbation due to gravity waves can be ascertained.

Acoustic sensors and electric field-mill for the study of electrostatic sound from thunderstorms, has been installed.

The current focus of research is the completion of the establishment of the Doppler-sounder array and collections of gravity-wave and acoustic data from severe storms. We are also focussing on collecting the beacon satellite data as well as satellite cloud pictures for studying gravity waves. Another aspect we are concentrating on is the collection of electrostatic sound data from thunderstorms.

During the FY-81 we plan to analyze and interpret the acoustic and gravity-wave data collected from our different systems. We plan to record and analyze wave data from our array of Doppler-sounders and use ray-tracing techniques to determine the location of the source. To complement the ionospheric data, we will use gravity wave information from satellite pictures, beacon satellite transmissions and ground level pressure sensors. We will thus have the combined picture of gravity waves at various levels in the atmosphere and may be able to determine the most effective way of monitoring gravity waves from severe storms. With regard to the electrostatic sound problem, we plan to map the sources of sound within the thunder cloud and their relationship with the electric-field distribution.

**Recommendations for New Research:** Detailed study of the thunderstorm using Doppler radar in association with the ionospheric Doppler-sounder to find any correlation between the two sets of data will be very helpful in understanding the generation of gravity waves from thunderstorms.

**TITLE:** Airborne Doppler Lidar Severe Storms System

**RESEARCH INVESTIGATOR:** J. W. Bilbro
EC32, Bldg. 4487
NASA/MSFC AL 35812
(205) 453-3941

**FY-80 ACCOMPLISHMENTS:**

During FY-80 a number of significant accomplishments were achieved. The signal processor built by Lassen Research of Manton, CA was received. The signal processor was incorporated into the Doppler lidar system and a series of tests were performed aimed at establishing a comparison with the filter bank processor which had been used previously. A paper on this comparison is being prepared for presentation in July at the meeting on coherent laser radar for Atmospheric Sensing, sponsored by the Optical Society of America (OSA). A joint meeting of the contractors involved in data interfacing for the severe storms test was held. Preliminary interface specifications were agreed upon. The simulation program has been completed and transferred to the PDP 11-35 where real time displays can be simulated. A science working group has been established and preliminary discussions relative to tests objectives have been held. Software for real time data collection and processing has been implemented and the microprocessor acquired for use in the central timing and control system. The lidar itself has completed a series of ground tests and has been sent to Raytheon to be refurbished.

**CURRENT FOCUS:**

The current efforts are aimed at developing the program test plan and defining post processing algorithms.

**PLANS FOR FY-81:**

The entire system will be integrated and an all up systems test will be performed in a ground based mode. Attempts will be made to simulate the aircraft conditions as closely as possible. Flight testing of the system will begin in June 1981. Participation in CCOPE is expected for the month of July.

**RECOMMENDATIONS FOR NEW RESEARCH:**

Continuation of testing with this system beyond the next three years will require replacement of the transmitter system. This will entail some development work in frequency stabilized TEA lasers.

**TITLE: AIRBORNE LIDAR SYSTEM DEVELOPMENT AND TESTING**

**RESEARCH INVESTIGATOR: M.C. KRAUSE - RAYTHEON COMPANY**
**528 Boston Post Road, Sudbury,Ma. 01776**
**(617) 443-9521**

## FY80 Accomplishments:

During FY80 the Airborne Lidar Program concentrated on the development of new sybsystems which will modify and expand the capabilities of the existing Lidar (CAT) system to perform the Severe Storms Measurements. These new subsystems include a side looking scanner, a Central Timing and Control System (CTCS), a new aircraft interface unit, and an off-axis telescope. Additionally, the Lidar was returned to Raytheon for refurbishment and repair.

The scanner consists of dual germanium wedges which scan the output beam 20 degrees fore and aft of a line perpendicular to the aircraft flight path. The scanner, which is controlled by the CTCS, is stabilized in roll and pitch to maintain a horizontal scan plane. Maximum scan rate is ≈.25 second with a variable dwell time depending on the number of pulses integrated. The CTCS, which interfaces all aircraft systems including the INS, Air Data Computer, ADDAS, and time code also controls the scanner, interfaces the signal processor, and formats and transfer by DMA all information to the PDP 11/35 data processor.

A detailed error analysis is being conducted to determine the error volume and measurement errors expected from the total system. This analysis is being performed in two parts consisting of (1) Spatial errors, which include LOS pointing, aircraft position and attitude, and alignment and (2) Temporal errors which include doppler measurement inaccuracies, correction for aircraft velocity, and vector velocity determination. Aircraft position, which is calculated 10 times per second utilizing ground speed and track angle and an initial starting point for each data run, should be accurate to within 4 meters in lat. and long.and 25 meters in altitude.
Accuracy of LOS position is ≈.4 deg in azimuth and elevation. Subsystem errors include static alignment, roll and pitch correction, wedge position, servo and gear train errors, and interval INS errors.

The combined errors in locating a measurement volume 10Km perpendicular to the aircraft flight path from two points spaced 7.5 Km along the flight path results in a ≈100m x,y, and z intersection error for single pulses. For a 50 pulse mean the intersection error volume is reduced to ≈15m in x,y, and z coordinates.

The Temporal error analysis is now in progress and should be completed by October.

FY81 Plans: During FY81 the new subsystems and refurbished LIDAR system will be ground tested in a semi-trailer NASA van to verify system performance and measure actual system pointing and measurement errors. In May 1981 the completed system will be shipped to NASA-Ames for installation aboard the CV-990, system calibration, and preliminary flight testing. When this phase is completed, the system will be ready to participate in the Severe Storm Measurement Program.

Recommendation for New Research: Following the present system development phase and 1981 flight testing, major improvement in system performance will depend on the development of a more powerful transmitter. The present transmitter is approaching the end of its lifetime, being more than 10 years old. State of the art transmitters should not only increase operating range but greatly improve performance in marginal backscatter conditions.

**Title:** **Scientific Overview of Doppler Lidar Program**

**Research Investigator(s) Involved:**

George H. Fichtl
John W. Kaufman
NASA Marshall Space Flight Center
Marshall Space Flight Center, AL 35812
205-453-0875 (FTS 872-0875)

**Significant Accomplishments FY80:**

The objectives of this effort are to scientifically support the FY81 flight verification of the airborne Doppler Lidar System, obtain fundamental data on small mesoscale and microscale phenomena with a view toward increasing our basic knowledge of these phenomena, and identify key scientific issues and needed data acquisition programs. During FY80 we will have organized the scientific support effort to the Doppler lidar verification project.

In April 1980 a meeting was held at the NASA Marshall Space Flight Center to explore the potential applications of the Doppler lidar to the atmospheric sciences. The participants included leading authorities in the atmospheric sciences in the area of meso and microscale meteorology. A major result of the meeting was a consensus that the presently configured MSFC Airborne Doppler Lidar System has the capability of acquiring detailed wind field data which would give the atmospheric scientist new and needed insight into micro and mesoscale flows. Furthermore, it was concluded that the range of phenomena that can be explored with the system is broad and includes convective flows, local circulations, atmospheric boundary layer flows, entrainment, atmospheric dispersion, industrial aerodynamics, and others. Specific conclusions of the April 1980 meeting are as follows.

1. In developing the FY 1981 test program plans for the Doppler lidar every effort should be made to coordinate tests with other measurement programs so as to obtain a sufficiently large "ground truth" data base for post flight evaluation of the Doppler Lidar System.

2. Participation of the Doppler Lidar System in the Cooperative Convective Precipitation Experiment (CCOPE) could result in unique data sets which could be used for system verification and at the same time significantly contribute to CCOPE scientific objectives.

3. A comprehensive error analysis of the system which specifies the accuracy of the system and representativeness of the wind data is needed.

4. Significant scientific benefits can be obtained by operating the Doppler lidar in other orientations than that currently planned for in the FY 1981 flight test program.

5. A systematic development of the airborne Doppler lidar will provide a strong tool for atmospheric wind measurement. The technology associated with this systematic development of the current system will have direct application to satellite systems for which the lidar also promises to be an effective instrument for atmospheric research.

6. During the acquisition of measurements of flows associated with phenomena characterized by clouds, it will be necessary to acquire additional data which can be used to determine the location and characteristics of the clouds, stage of development of these clouds and possibly, the evolution with time of clouds so that wind fields can be correlated with the dynamic intensity and stage in development.

7. Every effort should be made to include instrumentation in the FY 1981 test program to acquire independent measurements of water vapor content and aerosol properties in the field where measurements are to be taken.

8. The full impact of the Airborne Doppler Lidar System on the atmospheric sciences will not be realized unless the data (Doppler lidar and supporting data sets) from the FY 1981 and subsequent year test programs are systematically analyzed by the scientific community.

Subsequent to the April 1980 meeting, a plan for scientific support to the Doppler lidar verification effort was developed. This plan includes the formation of a science working group to support the FY81 verification test planning, execution, and subsequent post flight data analysis; and specifies milestones for science inputs to be made to the project relative to specification of requirements related to onboard data displays, post flight data processing and test flight data acquisition operations. We have completed specification of onboard data display requirements. A science working group meeting in support of the project is being planned for mid-to-late summer of 1980.

<u>Current Focus of Research Work:</u>

Present efforts are aimed at (1) finalizing requirements for post flight data processing, (2) identification of additional equipment for the Convair 990, (3) initial definition of FY81 flight test options.

Plans for FY81:

In FY81 we plan to define the FY81 flight test options for the verification of the Doppler lidar and acquisition of data for scientific analyses. This will include development of scientific priorities relative to data acquisition. We plan to support the actual flight tests by providing on-site meteorological consultation. Subsequent to the flight tests we plan to perform a preliminary data analysis to provide a scientific assessment of the Doppler lidar for development of new thrusts for FY 82 and follow-on years.

Recommendations for New Research:

Research plans for FY82 and follow-on years, to a large degree, will depend on the results of the FY81 flight test efforts. Future research that can now be identified includes (1) development of global and U. S. regional water vapor and aerosol climatologies, (2) systematic scientific analysis of Doppler lidar data from the FY81 and subsequent year flight test programs to assess the full scientific impact of this system on the atmospheric sciences.

**Title:** Analyses of CAT Wind Velocity Measurements as Acquired by the MSFC Airborne Doppler Lidar System

**Research Investigator(s) Involved:**

John W. Kaufman
NASA Marshall Space Flight Center
Marshall Space Flight Center, AL 35812
205-453-3104

**Significant Accomplishments FY80:**

The MSFC Coherent Doppler Lidar Wind Velocity Measurement System was flown aboard the Convair CV-990 airborne laboratory during the latter part of 1979 to obtain clear air turbulence (CAT) data. The flight experiments took place over the western part of the United States and the adjacent Pacific Ocean area. Preliminary analyses of these CAT data has shown that the Airborne Doppler Lidar Wind Velocity Measurement System is capable of acquiring wind velocity data by remote methods as anticipated. The initial examination of the CAT data and related aircraft inertial navigation system (INS) data has shown significant results. Primarily, emphasis has been placed on the comparison of lidar winds to those measured by the INS aboard the CV-990. Of the 29 records of CAT data gathered particular attention has been to flight data sets 18, 19 and 23. Basically, the data were examined as follows:

1. The time histories of wind velocities, air speed, ground speed, true heading, etc., were plotted.

2. The Doppler lidar backscatter signal return showing the mean wind speeds, the one-sigma deviation of the return scattered signals were plotted, wind direction, mean and eddy flows were plotted, etc.

3. Streamline analyses of the computerized (i.e., mathematical simulation winds) mean and eddy flow data were made.

4. Spectral fast Fourier transformation (FFT) of select wind speed samples were conducted.

5. A limited amount of wind velocity data, as measured by a conical scan technique, obtained by the lidar were compared to simultaneously measured rawinsonde velocity profile data.

During FY80 special attention was placed on methods to most expediently extract the original raw data, as recorded onboard the CV-990 for placement on a standard meteorological type data tape for analyses.

Current Focus of Research:

Continued analyses of the remotely detected Doppler lidar CAT winds and associated data are being carried out. From the results, it is anticipated that a technical paper(s) will be prepared.

Plans for FY81:

The second scientific working group meeting is scheduled for August 25 and 26, 1980. This is a planning meeting, as that of the first meeting held on April 1, 1980, where preparations will be made to participate in the Cooperative Convective Precipitation Experiment (CCOPE) during the summer of 1981. Again, the CV-990 aircraft with the onboard lidar will gather wind data in the vicinity of thunderstorms that develop over Montana. The CCOPE Program is being sponsored by the Water and Power Resources Service (WPRS) of the United States Department of Interior and the National Center for Atmospheric Research (NCAR), Boulder, Colorado. The initial CCOPE planning meeting was held in Denver on the 10th through the 12th of December 1979. At that time several scientists met who plan to participate in the Montana field program.

Recommendations for New Research:

A MSFC Conference Paper (CP) as prepared by Dr. George H. Fichtl, Mr. John W. Kaufman, and Dr. W. W. Vaughan, will be available very soon which provides an indepth description of the recommended research using the MSFC Airborne Doppler Lidar Wind Measurement System. This CP will be sent to all members of the lidar/wind scientific working group. Copies of this CP will be made available to other interested scientists by contacting Mr. Kaufman at the above address or telephone number.

## MESOSCALE/STORM FIELD EXPERIMENTS

**TITLE:** AVE-SESAME '79 Data Processing

**RESEARCH INVESTIGATORS:** Robert Turner
Kelly Hill

ES84
Marshall Space Flight Center, Alabama 35812
Telephone: (205) 453-4175/2570

**SIGNIFICANT ACCOMPLISHMENTS FY 80:**

NASA's Marshall Space Flight Center (MSFC) participated in a large interagency mesoscale and severe storms experiment identified as AVE-SESAME '79 (Atmospheric Variability Experiment - Severe Environmental Storms and Mesoscale Experiment 1979). A primary objective of NASA is to acquire carefully edited sets of rawinsonde data during selected severe weather events for use in correlative and diagnostic studies with satellite and radar data obtained during the same periods.

AVE-SESAME '79 data acquired on April 10-11, 19-20, 25-26 and May 9-10, 20-21, and June 7-8, 1979, are being edited and processed. These data are from approximately 20 supplemental and 23 standard rawin sites.

**CURRENT FOCUS OF RESEARCH WORK:**

The major focus for the coming months will be to complete the six unique data sets (see schedule sheet). Tapes and hard copies for each of the cases will be available upon request to Director, Space Sciences Laboratory, MSFC, Alabama 35812. Accomplishments of applied research using the unique data sets for mesoscale research will focus on the value of satellite sensors for detection of mesoscale systems.

**PLANS FOR FY 81:**

Study of the AVE-SESAME cases in conjunction with satellite data for a better understanding of mesoscale weather phenomena and their interactions with larger scales.

## AVE-SESAME-RAWINSONDE DATA PROCESSING SCHEDULE

| EXPERIMENT | RAW DATA CORRECTED | TRANSCRIBED | PUNCHED | RECORDED (TAPE) | DATA ERRORS | DATA TAPE RAW | DATA TAPE CONTACT | DATA TAPE 25 MB | 25 MB DATE REPORT DRAFT | 25 MB DATE REPORT PUBLISHED | QUICK-LOOK DRAFT | QUICK-LOOK PUBLISHED |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVE-SESAME I | C | C | C | C | C | C | C | C | C | C | C | C |
| AVE-SESAME II | C | C | C | C | C | C | C | C | C | P | C | P |
| AVE-SESAME III | C | C | C | C | C | C | C | C | C | P | C | P |
| AVE-SESAME IV | C | C | C | C | C | C | C | C | IP | | IP | |
| AVE-SESAME V | C | C | C | C | C | C | IP | IP | | | | |
| AVE-SESAME VI | C | C | C | C | IP | | | | | | | |

C = COMPLETED

IP = IN PREPARATION

P = IN PRINTING

## MESOSCALE/STORM FIELD EXPERIMENTS

**TITLE:** Special Mesoscale/Storm Field Network (TAMV'81)

**RESEARCH INVESTIGATORS:** Robert Turner
Kelly Hill
Greg Wilson

ES84
Marshall Space Flight Center, Alabama 35812
Telephone: (205) 453-4175/2570

**SIGNIFICANT ACCOMPLISHMENTS FY 80:**

NASA's Marshall Space Flight Center (MSFC) will participate in and manage a large mesoscale and severe storms experiment identified herein as TAMV'81 (Texas Atmospheric Mesoscale VAS Experi-1981). A special meso-$\alpha$ and meso-$\beta$ network is being planned that will allow horizontal and vertical observations of temperature, moisture, and winds on a scale comparable with VAS. The network will operate for three 24-hour special observing periods taking soundings every three hours. The three observing periods are planned for March-May of 1981 and will include at least one period of relatively clear, calm weather and two periods of severe storm and other precipitation events.

The present Rawin System (electron tube technology and electro-mechanical systems) are being reworked to insure minimum problems in the Field Experiment.

**CURRENT FOCUS OF RESEARCH WORK:**

The major focus for the coming months will be to continue to keep abreast of GOES, D, E, and F schedules. To continue refurbishing the Rawin Systems.

**PLANS FOR FY81:**

To manage and participate in the TAMV'81 experiment.

## MESOSCALE/STORM FIELD EXPERIMENTS

**TITLE:** Cooperative Convective Precipitation Experiment (CCOPE)

**RESEARCH INVESTIGATORS:** Robert Turner

Greg Wilson

ES84
Marshall Space Flight Center, Alabama 35812
Telephone: (205) 453-4175/2570

**SIGNIFICANT ACCOMPLISHMENTS FY 80:**

NASA's Marshall Space Flight Center (MSFC) will participate with its Rawin Systems in a large inter-agency mesoscale and storms experiment in the summer of 1981 in Montana (May 11-August 7). A primary objective of NASA is to support an effort to acquire mesoscale rawinsonde data during selected weather events to identify, describe and understand the most important aspects of many scale interaction events; hydrometer evolution, precipitation efficiency, origins of ice, entrainment, storm structure and the environment, storm initiation, atmospheric chemistry, and storm electrification.

**CURRENT FOCUS OF RESEARCH WORK:**

The major focus for the coming months will be to continue to keep abreast of CCOPE events and schedules. To identify scientific studies that can be conducted involving mesoscale as well as synoptic scale phenomena.

**PLANS FOR FY 81:**

Coordination with NCAR and WPRS for Rawin Systems and assistance when necessary, if funding is available.

1. OVERALL TITLE: ANALYSIS OF SATELLITE DATA FOR SENSOR IMPROVEMENT

2. SPECIFIC TITLE: ANALYSIS OF AVE-SESAME '79 DATA

3. INVESTIGATOR: T. Theodore Fujita
Department of the Geophysical Sciences
The University of Chicago
Chicago, Illinois 60637

4. PHONE NUMBER: (312) 753-8112

5. SIGNIFICANT ACCOMPLISHMENTS, 1979-80

A. Mapping of the Red River Valley Tornado Outbreak of April 10, 1979 --- AVE-SESAME '79 Day.

Fujita and Wakimoto (graduate student) arrived at Oklahoma City on April 11 in an attempt to fly over the tornado areas. Due to extremely dense dust storm, aerial photographic survey was performed on April 12 and 13. A four-color tornado map was completed which included 13 wind storms which occurred in the Red River Valley between 1500 and 2015 CDT (2100Z April 10 and 0215Z April 11) April 10, 1979.

* Color maps are to be distributed during the research review.

B. Precise Gridding of GOES/SMS Imagery in support of AVE-SESAME '79

Rapid-scan pictures were taken on April 10, 1979, at 3-minute intervals. Grid lines to be superimposed on these pictures were computed at 0-km (sea level) and at 12-km levels. Because of the orbital inclination and the spin axis deviation, both exceeded 5 degrees, the grid lines changed even within 3 minutes. Extremely accurate griddings have been achieved.

* Results are shown with slides.

C. Diabatic Analysis - A New Method for Predicting Tornado Outbreaks

A modified isentropic analysis was formulated and a test analysis of the AVE-SESAME '79 case on April 10, 1979, has been completed. Results revealed that a downslope wind on the diabatic surface is a promising predictor of tornado outbreaks.

* Copies of SMRP Report No. 183 entitled "Diabatic Analysis" are to be distributed during the review meeting (see Appendix C).

## 6. FUTURE PLANS AND RECOMMENDATIONS

A. To carry out AVE experiments over the western parts of the United States to investigate the nature of downslope winds, a new predictor of tornado outbreaks.

B. To develop Severe-Storm and Mesoscale Environmental Research Satellite (SMEARS) with improved sounding capabilities in the presence of high clouds. Such a satellite is extremely useful in detecting and tracking a downslope wind from the northeastern Pacific to the immediate vicinity of tornado areas..

C. To pursue diabatic analyses over the other parts of the world to determine the influence of giant mountains. The highland appears to be the best orography to be studied.

D. To conduct global analysis of diabatic charts in describing three-dimensional motions of the global atmosphere.

# APPLICATION OF THE AVE-SESAME DATA SETS TO MESOSCALE STUDIES

**Investigators:** David Suchman
Space Science & Engineering Center
University of Wisconsin, Madison, WI 53706
(608) 262-5772

Carlyle H. Wash
Space Science & Engineering Center
University of Wisconsin, Madison, WI 53706
(608) 263-3207

**Significant Accomplishments FY-80:** Funding begins June 1, 1980.

**Current Focus of Research Work:** The main objectives of this program as proposed are:

1. Derive low, middle and upper level wind sets from rapid scan GOES imagery during AVE-SESAME cases and develop techniques to combine satellite-derived winds with the AVE-SESAME radiosonde data to describe the evolution of synoptic and subsynoptic features associated with the convective outbreaks.

2. Map digital radar data of AVE-SESAME into satellite projection to conduct statistical studies interrelating GOES brightness and radar reflectivity.

3. Analysis of smaller-scale GOES brightness signatures which have been related to vigorous convective and severe weather.

**Plans for FY-81:**

1. We will begin to apply the AVE storm-scale rawinsonde data set plus rapid-scan satellite imagery to produce high quality wind sets in four dimensions by applying methods tested on GATE data to the mid-latitudes. We will be able to vary the time between images of our satellite winds to discern different scales of motion, use moisture profiles to better discriminate cloud layers in the vertical, and apply isentropic analysis to get a better feel for levels of motion of clouds (which do not necessarily coincide with pressure surfaces). These wind sets (when the cloud coverage permits) will yield a high resolution continuous picture of evolving vorticity and convergence patterns which can then be added to the standard thermodynamic approach to severe storm analysis and forecasting.

2. We will begin a detailed intercomparison of GOES digital data with surveillance digital radar and surface and aircraft reports (where appropriate). Digital radar data will be remapped into the satellite projection using techniques already developed at SSEC for GATE studies forming three colocated data sets (GOES VIS and IR and radar reflectivity). From this data set detailed statistics comparing GOES brightness and radar will be determined. Surface and aircraft reports of severe weather will also be plotted on a satellite projection to further interpret signatures in satellite brightness patterns. The goal of this phase of the work is the determination of brightness threshold for GOES VIS and IR alone, and various combinations of VIS and IR together to locate light, moderate and deep convective areas, and to determine confidence levels for these thresholds as a means of indicating their reliability for operational use.

3. In addition, we will combine satellite and radar data to better define small-scale thunderstorm features, relate them to surface reports, and then verify our findings with aircraft photos obtained at GLAS. The next step is to compare the satellite visual and digital information with that of digital radar and aircraft photos. In this way, two independent measures of a storm's intensity can be compared, calibrated, and then correlated to events at the surface. It is hoped that by further examination, signatures of the overshoots associated with severe weather, and the sensitivity of the satellite in detecting them, can be determined.

**Title: Storm-Environment Interactions Determined from AVE-SESAME and Satellite Data**

**Principal Investigator:** Henry E. Fuelberg
Department of Earth and Atmospheric Sciences
Saint Louis University
221 North Grand Blvd.
Saint Louis, Missouri 63103
314-658-3121

**Significant Accomplishments FY-80:**

Our primary thrust has been to describe the interactions that occur between large areas of intense thunderstorms and their surrounding environments. Special attention has been given to fluctuations in the environmental wind field that occur in the vicinities of storms.

During FY-80 the AVE 6 (May 1978) and AVE-SESAME 1 (April 1979) cases have been studied. Both were periods of special 3-h rawinsonde data and higher frequency satellite data. To describe the wind variability that occurred, the kinetic energy balance was computed for each observation time as were fields of kinematic quantities such as divergence and vorticity. Only NWS rawinsonde data have been used thus far in the AVE-SESAME 1 study because we wished to consider the synoptic scale storm environment.

The results of these and previous studies reveal that major fluctuations in wind velocity occur in the storm environments. Enhanced low level convergence, upper level divergence, upward vertical motion and the formation of upper level wind maxima have been observed. Major changes in the kinetic energy balance also occur. These fluctuations appear to be related to feedback mechanisms from the storms.

**Current Focus of Research Work:**

Our current focus is to investigate the feedback processes by which storms modify their environmental wind field. Given this understanding, the effects of such storms can be parameterized into numerical forecast models such as the LFM. Additional diagnostic studies, using data at shorter time and space intervals provided by AVE-SESAME rawinsonde and satellite sources, are being conducted.

**Plans for FY-81:**

A. The variability of the momentum field during AVE-SESAME 1 will be studied using the combination of NWS and special site data in order to describe the subsynoptic scale interactions between storms and their environments.

B. Explanations will be sought for the difference in the energy budgets that have been computed for the various cases.

C. The relative strength and variability of the divergent and nondivergent wind components will be determined during the intense convective period of AVE 4.

D. An error analysis will be performed on all quantities computed in order to assess their reliability.

**Recommendations for New Research:**

A. Storm-environment interactions at a data spacing of around 100 km should be investigated using the smallest scale AVE-SESAME data.

B. When VAS sounding data become available they should be used to investigate small scale wind features through use of the thermal wind equation and boundary layer wind equations. The VAS data will have time and horizontal space resolutions that far surpass anything presently available. VAS data will originally be used in a research mode, but at a later date, they can be used to monitor the atmosphere's thermal and flow pattern for forecasting purposes.

**Summary:**

Our research on storm-environment interaction proceeds in a "telescoping" manner from the synoptic scale (current work) down to the storm scale. The feedbacks of storm areas on their environmental flow fields is receiving special attention in that these processes can someday be parameterized in the NWP models.

**Titles:** 1. **Diagnostic Analysis of the Environment of Severe Storms Using AVE-SESAME and Satellite Data.**
2. **Processing AVE-SESAME Sounding Data.**

**Principal Investigator:** **Dr. James R. Scoggins**
**Department of Meteorology**
**Texas A&M University**
**College Station, Texas 77843**
**713-845-7671**

Significant Accomplishments FY-80: The following reports were prepared.

Published

1. AVE-SESAME I: 25-mb Sounding Data. Gerhard, Fuelberg, Williams, and Turner. NASA TMX-78256.
2. A Preliminary Look at AVE-SESAME I Conducted on April 10-11, 1979. Williams, Scoggins, Horvath, and Hill. NASA TMX-78262.

In Publication

3. A Preliminary Assessment of the Accuracy of Selected Meteorological Parameters Determined from Numbus 6 Satellite Profile Data. Scoggins and Petti.
4. AVE-SESAME II: 25-mb Sounding Data. Williams, Gerhard, and Turner.
5. AVE-SESAME III: 25-mb Sounding Data. Williams, Gerhard, Gilchrist, and Turner.
6. A Preliminary Look at AVE-SESAME II Conducted on 19-20 April 1979. Williams, Horvath, and Turner.
7. A Preliminary Look at AVE-SESAME III Conducted on 25-26 April 1979. Williams, Horvath, and Turner.
8. The Development of Wind Shear, Vertical Motion, and Convective Instability in Relation to Convective Activity. Davis and Scoggins. In preparation.

Submitted as NASA Reference Publications for Research
Supported by Army Research Office, Durham, N.C.

9. Comparisons Between Nimbus 6 Satellite and Rawinsonde Soundings for Several Geographical Areas. Cheng and Scoggins.
10. Determination of Wind From Nimbus 6 Satellite sounding Data. Carle and Scoggins.
11. Atmospheric Structure Determined from Satellite Data. Knight and Scoggins.
12. A Comparative Analysis of Rawinsonde and Nimbus 6 and Tiros N Satellite Profile Data. Scoggins, Carle, Knight, Moyer, and Cheng.

As is evident from the above reports, the past year has been devoted primarily to data processing and to concluding the documentation of studies nearing completion. Funding was received only recently for additional analysis work and significant results are not yet available. However, initial analysis of AVE VII and AVE-SESAME I is underway. To date, our efforts have been on gridding the basic data at 50-mb intervals to 100 mb, and on computing vertical motion.

Current Focus on Research Work: Unfortunately, our focus has been on data processing because we had no funds for analysis until recently. Our focus will change toward analysis in the months ahead.

Plans for FY-81:

1. Complete processing the AVE-SESAME data.

2. Perform diagnostic analyses of the environment of severe storms using AVE VII and AVE-SESAME I data.

3. Participate in a NASA-sponsored mesoscale experiment in the Spring of 1981.

Recommendations for New Research:

1. The interpretation and utilization of quantitative satellite sounding data in analysis and forecasting seem to need much additional consideration. Specifically, the integration of satellite and conventional data into a unified data set has not been satisfactorily accomplished, and a study is needed to determine when, where, and under what conditions satellite data can be used most effectively.

2. Mesoscale numerical models are needed to help synthesize observed conditions, and for forecasting over short time periods (less than 12 hr).

TITLE: Mesoscale Winds and Rainfall Rates in Areas of Severe Storms Determined from Satellite Imagery and AVE-SESAME Rawinsonde Data

INVESTIGATORS: R. Jayroe EF36/MSFC 205/453-5609
G. Wilson ES84/MSFC 205/453-2570

FY-80 ACCOMPLISHMENTS:

One test area (200 x 200 picture elements) has been selected and analysed. The wind velocity computational software for two approaches has been developed, but the diagnostic software (for identifying sources and magnitudes of problems) will by necessity be in a continuous state of development. For the test area, cloud velocities have been computed using manual cloud tracking, by interpolating Rawindsonde profiles to the test area and by computer matching of template areas between the images over the same ground scene separated in time. At present, reliable velocity profiles cannot be computed from the satellite imagery for two reasons: (1) there appears to be a consistent 15 - 20 pixel error in the coordinates of the infrared data relative to the visible data, (2) software is needed that relates I.R and visible data, sun angle, cloud thickness and emissivity to altitude. However, if the cloud velocity components are evaluated independent of altitude; the qualitative and quantitative aspects of the results are in good agreement. Also, two approaches have been identified for eliminating spurious results due to banding and areas not covered by clouds.

CURRENT FOCUS OF RESEARCH WORK:

The current focus of the work involves evaluating the effects of various parameters on the computation of cloud velocities. The parameters include the time difference between sequential images, using directional derivatives versus a non-derivative template matching approach, template area size, search area size and derivative template area size. Also, efforts are underway to obtain and implement cloud target height determination software.

FY81 PLANS:

The FY81 plans are to expand the test area coverage to surround and fill in the gaps between the Rawindsonde launch sites. The second step is to use the satellite derived wind profiles from the expanded test area to predict what the Rawindsondes would measure and perform an evaluation of the predicted versus measured results. If the results favorably compare, the Rawindsonde data will be interpolated over the test area to discern and evaluate the difference as compared to the satellite derived velocity measurements.

NEW RESEARCH RECOMMENDATIONS:

Although somewhat premature, planning could be formulated for the design and fabrication of a special purpose hardware device to compute wind velocity profiles from satellite imagery. This will be a requirement if the approach is successful and timely results are to be obtained. However, more immediate recommendations will probably surface as the effort has a chance to progress.

**TITLE:** Diagnostic Analysis of Important Mesoscale Systems in AVE-SESAME I

**RESEARCH INVESTIGATORS:** Kelly Hill
Gregory Wilson
ES84
NASA/MSFC
Huntsville, Alabama 35812
(205) 453-2570 or FTS 872-2570

**SIGNIFICANT ACCOMPLISHMENTS FY-80:**

The unique AVE-SESAME I data have been extensively analyzed to identify those structural features and dynamical processes important to the development of severe convection during April 10-11, 1979.

Important mesoscale systems embedded and moving through an intense synoptic scale pattern were instrumental in creating environmental conditions favorable for severe convection. The dynamics of these mesoscale systems have been examined within the context of budget equations for moisture, kinetic energy, and sensible heat.

Preliminary results clearly show that these intense mesoscale systems controlled severe storm development and must be accurately predicted to improve forecasts of convective activity within mesoscale time and space domains.

**CURRENT FOCUS:**

Perform an extensive analysis of the mesoscale moisture, kinetic energy, sensible heat budgets in those areas affected by severe convection and intense mesoscale perturbations.

**FUTURE PLANS:**

Combine the above analyses with quantitative satellite data including cloud motion vectors, rainfall rates, temperature and moisture soundings, and multispectral imagery to refine the mesoscale structure and dynamics of the atmosphere as it relates to severe convection.

**RECOMMENDATIONS FOR FOLLOW-ON RESEARCH:**

Examine the possibility of numerically simulating the important mesoscale systems identified in AVE-SESAME I data using both operational numerical prediction models (i.e., LFM) and special mesoscale models.

**TITLE:** MESOSCALE STRUCTURE AND DYNAMICS IN RELATION TO SEVERE STORM DEVELOPMENT


**PRINCIPAL INVESTIGATOR:** Gregory S. Wilson
ES84
NASA/MSFC
Huntsville, AL 35812
(205) 453-2570 or FTS 872-2570

**CO-INVESTIGATORS:**

Kelly Hill, ES84, NASA/MSFC, Huntsville, AL 35812, (205) 453-2570; FTS 872-2570

Bob Jayroe, EF36, NASA/MSFC, Huntsville, AL 35812, (205) 453-5609; FTS 872-5609

Bob Atkinson, EF36, NASA/MSFC (GE), Huntsville, AL 35812, (205) 453-2632; FTS 872-2632

Bob Turner, ES84, NASA/MSFC, Huntsville, AL 35812, (205) 453-4175; FTS 872-4175


**SIGNIFICANT ACCOMPLISHMENTS FY-80:**

I. DIAGNOSTIC ANALYSIS OF THE MESOSCALE ENVIRONMENT OF SEVERE STORMS USING AVE/SESAME AND SATELLITE DATA:

** Determination of the dynamical processes involved in the interactions between severe storms and their environment.

"Thunderstorm-Environment Interactions Determined with Three-Dimensional Trajectories," NASA Reference Publication 1054, January 1980.

"Interactions Between Lines of Severe Thunderstorms and Their Synoptic-Scale Environment," presented at the 11th Conference on Severe Local Storms, October 1979.

"The Structure and Dynamics of Important Mesoscale Systems Influencing the Red River Valley Tornado Outbreak of April 10, 1979. In Press.

** Development of a Severe Storm Climatology Using Manually Digitized Radar (MDR) and Satellite Data.

"Monthly and Seasonal Occurrences of Potential Flash Flood-Producing Rains Determined from Manually Digitized Radar Data," to be presented at the 8th Conference on Weather Analysis and Forecasting, June 1980.

** Development of a new minicomputer system capable of interactive processing and data-base management of AVE/SESAME data.

II. MEDIUM-RANGE (6-48 H) THUNDERSTORM AND SEVERE WEATHER PREDICTION SYSTEM:

** Refinement of an objective technique for forecasting thunderstorm intensity in the U.S. utilizing LFM numerical predictions.

"Medium-Range Forecasting of Thunderstorm Location and Severity Using Regional-Scale Atmospheric Structure and Dynamics Predicted by the LFM2 Model," presented at the 11th Conference on Severe Local Storms, October 1979.

"Application of an Objective Technique for Medium-Range Prediction of Thunderstorm Intensity to the April 10, 1979, Tornado Outbreak." In Press.

** Operational implementation of the prediction system at the National Severe Storms Forecast Center and the Air Force Global Weather Center for testing, evaluation, and refinement.

III. MESOSCALE WINDS AND RAINFALL RATES IN AREAS OF SEVERE STORMS DETERMINED FROM SATELLITE IMAGERY AND AVE/SESAME DATA:

** Development of an objective technique for automatic determination of cloud motion fields of equal or better accuracy/spatial coverage than interactive man/machine methods.

IV. SCIENTIFIC SUPPORT/DESIGN OF MESOSCALE FIELD PROGRAMS (AVE/SESAME, SATELLITE (VAS)/SEVERE STORM SPECIAL MESONET, AND CCOPE):

"NASA's Participation in the AVE/SESAME '79 Program," Bulletin of the American Meteorological Society, November 1979.

"AVE/SESAME '79 Rawinsonde Data--Processing, Accuracy, and Availability," presentation at the 1980 SESAME Data Users Workshop, January 1980 (NOAA/ERL, Boulder).

CURRENT FOCUS:

I. Finalization of trajectory work, severe storm climatology, and Red River Valley Tornado Outbreak research for journal publication.

II. Analysis of the operational utilization of the thunderstorm forecast system to determine verification statistics and areas for improvements.

III. Refinement of automatic cloud motion techniques and the preparation of data/software for satellite/MDR rainfall rate determination.

IV. Acquisition and preparation of equipment and operational requirements for the upcoming Satellite (VAS)/Severe Storm and CCOPE mesoscale field programs.

FUTURE PLANS:

I. Integrate diagnostic results from mesoscale/synoptic diagnostic work to produce a descriptive-dynamical model of thunderstorm-environment interactions and
Improve radar (MDR)-derived severe storm climatology by using a larger data base and incorporating satellite data.

II. Upgrade thunderstorm/severe weather forecasting systems utilizing the results from operationally derived verification statistics.

III. Begin to utilize the automatic cloud motion vectors and rainfall rates in mesoscale diagnostic work.

IV. Execution of the Satellite (VAS)/Severe Storm and CCOPE mesoscale field programs.

**RECOMMENDATIONS FOR FOLLOW-ON RESEARCH:**

I. Investigate modifications to numerical models based upon diagnostically determined thunderstorm-environment interactions.

II. Investigate the utilization of the medium-range thunderstorm/severe weather forecast system as an operationally available guidance product.

III. Investigate modifications to numerical models based upon improved initialization with automatically determined cloud motion vectors, rainfall rates, and mesoscale temperature and moisture profiles determined from space measurements.

Incorporate the above measurements into future short-range severe weather forecast techniques/systems (i.e., McIDAS at the National Severe Storms Forecast Center).

IV. Continue to support satellite/severe storms field programs with the purpose of providing an improved understanding of severe storms through better interpretation/utilization of space measurements.

**Title: Diagnostics of Severe Convection and Subsynoptic Scale Ageostrophic Circulatio ıs**

**Research Investigator:** Donald R. Johnson
Space Science and Engineering Center
The University of Wisconsin
1225 W. Dayton Street
Madison, WI 53706 (608/262-2538)

**Significant Accomplishments FY-80:**

The principle research thrusts during FY-80 were numerical and diagnostic studies of ageostrophic motion attending jet streak circulations and creation of conditions favorable for deep convection. Both theoretical and numerical analyses of steady adiabatic inviscid motion of jet streaks have provided insight into ageostrophic motion and mass momentum adjustment. In the balance of steady, isentropic flow, the inertial components of ageostrophic motion are coupled with the distribution of absolute vorticity and kinetic energy superimposed on the geostrophic state. The variations of vorticity lead to an inertial component of ageostrophic motion along the geostrophic flow while the gradient of kinetic energy associated with finite length jets leads to components of ageostrophic motion normal to the basic geostrophic current. Regions of static stability change associated with propagation of jet streaks have been identified with these two ageostrophic components and mass-momentum adjustment.

Through determination of the momentum distribution from an assumed mass distribution of a jet streak within an hybrid isentropic-sigma coordinate channel model, these components of ageostrophic motion have been identified and studied in initialization experiments and numerical integration. Realistic direct and indirect ageostrophic mass circulations are isolated in the initial state structure. These circulations maintain integrity during numerical integration and suppress the dispersion of momentum and kinetic energy during the early time periods. An accurate simulation of atmospheric balance that includes ageostrophic motion is essential in order to accurately simulate frontal and precipitation processes in mesoscale numerical weather simulation.

In a related effort, the design and testing of a finite difference method of comp·ting the pressure gradient force over elevated terrain has been completed. This method, which insures momentum and energy conservation, is a combination of a scheme proposed by Phillips and a flux form which determines the pressure gradient force from the surface integral of pressure stresses. A comparative study of this method with four others establishes that the combined method yields excellent results for mass-momentum adjustment of jet streaks propagating over elevated terrain. The pressure, wind fields and the developing circulation in the lee of the mountains maintain their integrity in contrast to the other methods where considerable noise develops throughout the numerical integration. This experiment is a cooperative effort with Dr. Louis Uccellini of Goddard.

In our initial studies of the AVE-IV case of severe weather, the isallobaric component of ageostrophic motion has been determined for the various isentropic levels. However, inaccuracies in the data and/or truncation errors from the finite difference estimations have produced some inconsistencies, particularly at the upper isentropic levels. The isallobaric wind field in the lower isentropic layers displays isallobaric ageostrophic motions associated with regions of low-level convergence and severe weather. Such results indicate that the mass-momentum adjustment associated with propagating hyperbaroclinic zones and isentropic layers is directly linked to the lower troposphere through isentropic mass circulations. A data set with corrections is being furnished by Marshall Space Flight Center to assist in our efforts to accurately isolate the forcing of ageostrophic motion at all isentropic levels through inertial and isallobaric components.

Current Focus of Research Work:

The current focus is the study of the forcing of severe storms by a combination of large-scale mass-momentum adjustment, release of latent heat and boundary processes through the use of the AVE-IV data sets and numerical simulation. The relative importance of the components of ageostrophic motion associated with various physical processes is being ascertained.

Plans for FY-81:

The efforts during FY-81 will be to continue the numerical simulation studies of ageostrophic motion with a hybrid isentropic-sigma coordinate model developed at the University of Wisconsin. A primary effort is the accurate inclusion of viscous and diabatic processes to insure that the physical components of ageostrophic motion are well simulated while noise and computational modes are suppressed. The results thus far indicate the use of conservative forms of transport relations for mass, momentum and energy are important in the suppression of noise during numerical integration. Comparative studies of mass-momentum adjustment and ageostrophic circulations will be conducted to determine the relative importance of adiabatic, diabatic and viscous processes under the influence of terrain, friction and release of latent heat.

Theoretical work on the structure of symmetric instability of circulations transverse to a jet streak within the isentropic framework has revealed that the usual instability criteria (negative potential vorticity) should be modified to include the effects of ageostrophic departures and lateral variations of mass (an inverse static stability measure). Preliminary results from a case study indicate that the lateral variations of mass play an important role in determining whether symmetric instability occurs. In the case study occurring on 23 April 1968, the addition of this term more correctly delineated the regions of severe weather development. The analysis will be applied to the AVE-IV data set as soon as the corrections are made to remove errors and achieve internal consistency.

The analysis of the AVE-IV data set to determine the inertial and isallobaric components of ageostrophic motion associated with the jet streak propagation and development of severe weather will be finalized. Concurrently, an attempt will be made to study the relative importance of diabatic processes in the vertical mass transport and modification of the isallobaric wind structure. During the process of latent heat release, isentropic surfaces may be displaced vertically, thus changing the pressure gradient force on the isentropic surface and inducing isallobaric components associated with this process. At the same, the generation of kinetic energy at this scale will be assessed in both the modeling and diagnostic efforts. The lateral variations of the mass distribution and the ageostrophic motion will be studied carefully in both diagnostic and numerical simulations to ascertain the relative importance of these features in the determination of the symmetric stability of jet streak structures.

**Recommendations for Follow-on Research:**

Through the inclusion of moist diabatic processes associated with latent energy release and friction in the hybrid isentropic-sigma coordinate model being used for these studies, the relative role of the various components of ageostrophic motion associated with inertial, isallobaric and diabatic processes and friction should be assessed for a variety of mesoscale atmospheric structures. The resolution of the hybrid model should be increased in order to more accurately simulate the modes through which mass circulations attending deep convection become linked to larger scale circulations. Case studies of severe weather using AVE and SESAME data should be conducted in order to study mass-momentum adjustment in both observed- and numerically-simulated structures. A comprehensive analysis of bias and random errors from observational and data assimilation systems should be conducted in order to assess the capabilities and limitations of these systems for inference and prediction of atmospheric processes at the mesoscale.

# B. CLOUD PHYSICS

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## CLOUD MICROPHYSICAL PROCESSES

**RESEARCH INVESTIGATORS:**

B. Jeffrey Anderson
Vernon W. Keller
Otha H. Vaughan
James M. Carter (University of Tennessee Space Inst.)
David A. Bowdle (USRA)

Atmospheric Sciences Division, ES83
Marshall Space Flight Center
Alabama 35812
205-453-5218

SIGNIFICANT ACCOMPLISHMENTS IN FY80:

1. Two experiments were successfully flown on the NASA KC-135 aircraft May 6-15, 1980. One experiment studied ice crystal growth from the liquid, the other studied the decay of turbulent air motions. The equipment for both experiments was built in-house.

2. Equipment and procedures for gravimetric evaluation of a precision low-gravity prototype saturator to better than 1% were developed.

3. A prototype static diffusion chamber for laboratory experiments on the stable levitation of charged water drops was designed and constructed from surplus equipment.

4. Hardware installation and software development for studies of the ice multiplication mechanism and the growth of ice crystals from the vapor were continued. A laser backscatter depolarization detector for ice crystals was constructed in-house and installed.

5. The theory of cloud droplet growth was extensively modified and a publication is in preperation.

6. Three papers for publication and four for presentation at the VIIIth International Cloud Physics Conference were prepared to report current and previous work.

CURRENT FOCUS OF RESEARCH WORK:

Emphasis is placed on the application of ground laboratory and low gravity research methods to solve problems of immediate interest in cloud physics. Primary studies are directed at the initiation and evolution of the ice phase in clouds and the development and interactions of aerosols and small cloud drops.

PLANS FOR FY81:

1. Continue analysis of data from the KC-135 flight experiments and conduct additional flight and ground based experiments to develop an understanding of the role of convection in ice crystal growth from the liquid.

2. Finalize the hardware and data handling software development required for the ice multiplication experiment. Determine the effect of adding surfactants and solid particulates to the ice multiplication environment.

3. Upgrade and calibrate the electric field levitation chamber and supporting equipment and begin preliminary aerosol scavenging expriments.

4. Begin calibration and ice crystal growth studies with the static diffusion chamber.

RECOMMENDATIONS FOR NEW RESEARCH

. Determine the magnitude and sign of the vertical flux of atmospheric aerosol near the earth's surface as a function of the turbulent (microscale), diurnal (mesoscale), synoptic (macroscale) and seasonal time scales for aerosol between about 0.1 and 10 μm diameter in various geographical locations.

2. Develop improved instrumentation for determining the ice content of clouds.

# RESEARCH ACTIVITIES RELATED TO ICE MULITIPLICATION

James M. Carter
University of Tennessee Space Institute
ES83
Marshall Space Flight Center, Alabama 35812
205-453-5218

## SIGNIFICANT ACCOMPLISHMENTS FY-80

The major effort, since the last review, on the ice multiplication research problem has been directed toward installation and checkout of hardware which facilitate this research endeavor. A laser backscatter depolarization detector system was constructed and installed. Work with this system has shown that some additional electronic hardware is going to be needed as the scattering seen from the mixed phase water/ice cloud is not as pronounced, from the ice, as would be desired. This additional circuitry will include a counter which will show coincidence counts on the two channels of the backscatter detector.

A Particle Measuring System dual size range, particle sizing spectrometer was installed inside the coldbox. This device provides a measure of the size distribution of the water droplets in the mixed phase cloud. This device showed in one test that with the addition of oliec acid vapor into the coldbox, the number of particles of size 40 microns diameter doubled in concentration. Follow up testing to confirm this modification to droplet number from another approach proved to be inconclusive.

Planning for adding a microprocessor based data acquisition and analysis capability to the ice multiplication setup was firmed up and the data acquisition software has been written and debugged. This will be put on line when all the hardware is available.

## CURRENT FOCUS OF RESEARCH EFFORT

The present effort is directed to firming up the support hardware and to make the system more stable from a time/temperature standpoint. I am also looking into the possibility of doing electrical measurements in conjunction with the other on-going measurements. This would look at charge seperation processes during the rime accretion.

## PLANS FOR FY-81

The current plans now for this next year are centered around determining the effect of adding surfactents, solid particles, and maybe gases to the ice multiplication process environment. The electrical measurements will be done as a parallel operation. The work will look at changes to the ice multiplication process with changes to the conditions of the environment, the aim still being to identify the physics of the process.

**TITLE:** Warm and Cold Cloud Processes, NAS8-33131

**RESEARCH INVESTIGATOR:** David A. Bowdle, USRA
ES83/MSFC, AL 35812 - 205-453-5218

**SIGNIFICANT ACCOMPLISHMENTS FY-80**

1. Developed equipment and procedures for gravimetric evaluation of a precision low-gravity prototype saturator to better than 1%.

2. Designed and constructed a prototype static diffusion chamber for laboratory experiments on the stable levitation of charged water drops.

3. Assisted in the Critical Design Review process for the MSFC Atmospheric Cloud Physics Laboratory (ACPL) formerly under development for the Space Shuttle by General Electric.

**CURRENT FOCUS OF RESEARCH WORK**

1. Numerical solution of the equations from the refined theory of activation of mixed composition cloud condensation nuclei (CCN) aerosols.

2. Proof of concept experiments for stable drop levitation in the prototype static diffusion chamber.

**PLANS FOR FY-81**

1. Upgrade and calibrate the levitation chamber and supporting equipment.

2. Literature review of scavenging by water drops.

3. Preliminary scavenging experiments with the levitation chamber.

4. Literature review of interactions between cloud microphysical phenomena and atmospheric electrical effects.

5. Preliminary experiments on electrical charge equilibrium and charge transfer mechanisms using the levitation chamber.

**RECOMMENDATIONS FOR NEW RESEARCH**

1. Determine the magnitude and sign of the vertical flux of atmospheric aerosol near the earth's surface as a function of the turbulent (microscale), diurnal (mesoscale), synoptic (macroscale) and seasonal time scales for aerosol between about 0.1 and 10 μm diameter in various geographical locations.

# CLOUD PHYSICS STUDIES IN LOW GRAVITY ON THE KC-135

**RESEARCHERS:** Dr. Vernon Keller
ES83, MSFC, AL 35812
205-453-0941

Mr. Otha H. Vaughan
ES83, MSFC, AL 35812
205-453-5218

Dr. John Hallett
Desert Research Institute
Reno, Nevada 89506
702-972-1676

## RESEARCH OBJECTIVES:

1. Examine the effect of reduced convection on ice crystal growth from liquid.

2. Observe turbulence decay and droplet motion relationships in low gravity.

## ACCOMPLISHMENTS:

During FY-80 the crystal growth equipment was extensively modified in-house. The droplet motion experiment was conceived and assembled in-house. Both experiments were successfully flown on the NASA KC-135 aircraft May 6-15, 1980.

## CURRENT FOCUS AND PLANS FOR FY-81:

The 16mm-movie films from the KC-135 flights are now being analyzed. The experiments will be duplicated in the laboratory and results will be compared. Additional KC-135 flights are planned.

**Title:** Influence of Convection and Ventilation on Free Growth of Dendrite Crystals from Solution

**Research Investigator:** Dr. John Hallett
Desert Research Institute
Atmospheric Sciences Center
P. O. Box 60220
Reno, Nevada 89506
(702) 972-1676

**Progress:**

The free growth of dendrites in a uniformly supercooled solution has been examined using cine photography with a Schlieren optical system. Crystals were grown in the bulk of the solution from a centrally located capillary tube and were nucleated at the liquid interface by a liquid nitrogen cooled wire. Crystals propagated along the tube, the slower growing orientations eliminated, and emerged at the tip, usually growing parallel to the tube direction. For both sodium sulfate decahydrate from its solution and ice from sodium chloride solution, growth rate and fineness of the dendrites increased with supercooling. In sodium sulfate, upward convection of the bouyant, depleted solution occurs; downward convection was observed for the rejected, more concentrated sodium solution. In both cases there was a spatial and temporal delay in the release of the convective plume from the moving dendrite tip; growth velocities differed depending on the orientation of the dendrite growth direction to the direction of the convecting plume. Fastest growth was achieved by growth into the direction of the convecting fluid. In order to investigate the role of forced ventilation on the growth characteristics, a system has been evolved whereby the capillary tube is moved horizontally as the dendrites emerge from its tip. This procedure gives dendrite velocities through the supercooled solution up to ten cm. per second. The role of forced and natural convection on the growth characteristics of dendrites and its relation to the production of secondary crystals has been examined. A low g experiment will examine the differences between this growth and a reduced convective regime where molecular transport is the dominant transfer mechanism.

## INTERNATIONAL WORKSHOP ON CLOUD CONDENSATION NUCLEI MEASUREMENTS


**Research Investigators:**

Warren Kocmond
Fred Rogers
Ulrich Katz
James Hudson

Desert Research Institute
Atmospheric Sciences Center
P. O. Box 60220
Reno, Nevada 89506
702-972-1676

James Jiusto

Dept. of Atmospheric Sciences
State University of New York at Albany
Albany, New York 12222
518-457-3986


**Significant Accomplishments:**

This effort is just beginning. Contractual arrangements were completed in May, 1980. The Steering Committee for the workshop has been formed. It consists of seven senior scientists from various institutions in the United States, Canada, and Israel.

**Current Focus and Plans for FY81:**

Preparations are underway for holding the workshop in Reno, Nevada from October 6th to the 17th, 1980. Approximately forty two participants and seventeen separate instruments for characterizing cloud condensation nuclei are expected. It is hoped that the workshop will accomplish two primary objectives, provide an intercomparison of the various types of instruments and, second, perform a scientifically meaningful experiment which will be selected by the steering committee in the near future.

# C. ATMOSPHERIC ELECTRICITY (LIGHTNING)

TITLE: SEVERE STORM ELECTRICITY

RESEARCH INVESTIGATORS:

Dr. W. David Rust, NOAA/NSSL, Norman, OK 73069, (405)360-3620, FTS 736-4916.

Mr. William L. Taylor, NOAA/NSSL, Norman, OK 73069, (405)360-3620, FTS 736-4916.

Dr. Roy T. Arnold, UNIVERSITY OF MISS., University, MS 38677, (601)232-7046.

Dr. William W. Vaughan, NASA/MSFC, Huntsville, AL 35812, (205)453-3100.

Dr. Bernard Vonnegut, SUNYA, Albany, NY 12203, (518)457-4607.

ACCOMPLISHMENTS FY 80

A. Data Acquisition Changes from FY 79

- 1980 Spring Program at NSSL is emphasizing storm electricity.
- Additional optical detectors built and installed: type flown on NASA U2, NOSL type modified for faster risetime and less circuit ringing, television camera and optical detector combination.
- NASA U2 overflight support including ground measurements at SEB and mobile laboratory and aircraft vectoring (see Remote Observations of Severe Storms and NOSL reports).
- Instrumentation of larger intercept van as mobile laboratory (see Storm Intercept report).
- L band (23 cm wavelength) radar installed at storm electricity building (SEB) at NSSL and modified for selectable linear and circular polarization for lightning radar echo studies.

B. Summary of Preliminary Analysis of 1979 Data

1. Squall line storm, 6 June 1979
   - 30 minute period of dual Doppler and lightning activity.
   - Storm had strong gust front (≈ 50 kts), no significant rotation, reflectivity and maximum updraft velocity nearly constant, linearly decreasing CG flashing rate, and significant increase in IC rate.
   - Over 300 flashes of which 38% were CG (IC:CG=1.6), 11% of CG's had continuing current (CC), average flashing rate ≈11 $min^{-1}$.

2. Severe storm, 20 June 1978
   - large hail, mesocyclone (i.e., large, rotating updraft), and supercell characteristics; discharge processes within the cloud predominately located around the mesocyclone where there were large gradients of reflectivity and velocity.

3. Radar observations of lightning with radar
   - Simultaneous $\Delta E$, optical, VHF impulses, and echoes from lightning have been obtained.
   - Lightning detected out to ranges of nearly 300 km at altitudes in excess of 10 km and with lengths of ≈100 km.
   - Observed abrupt increases in radar echoes apparently associated with return strokes, K-changes, and during CC.
   - Most data obtained this year are yet to be analyzed.

4. Positive CG's in severe storms
   - 1979: +CG's with visual or television documentation number <10υ in 5 storms, but we have numerous other ΔE waveforms suggestive of +CG's.
   - 1980: seeing +CG's again, data yet to be analyzed.
   - Indication that CG's from back-sheared anvil, mesocyclone, and downwind anvil may often be positive.

C. Other investigators performing electricity experiments at NSSL

Dr. C. Church, Purdue University: corona measurements beneath severe storms utilizing multistation network
Dr. R. Orville, SUNYA; Dr. M. Brook, NMIMT; and O. Vaughn, NASA/MSFC - U2 overflights
M. Maier, NOAA/NHEML - CG flash location
N. Crabill, NASA/Langley - hazards to aviation
V. Mazur, University of Oklahoma - L band lightning echoes

## CURRENT FOCUS OF RESEARCH WORK

We are presently in the midst of the severe storm season and field program, which began in mid-April and will terminate the end of June. Immediately following that, we will again emphasize data reduction and analysis. We are also prepared to provide ground measurements for U2 overflights during the summer if they occur.

## PLANS FOR FY 81

We will continue field observations during the 1981 spring severe storm season and increase analyses of data. We anticipate continued collaboration with several colleagues interested in severe storm electricity and invite others involved with severe storm research to join us.

## RECOMMENDATIONS FOR NEW RESEARCH

A. Initial study of ELF techniques for possible use with satellite sensors (see W. Taylor report).

B. A meaningful U2 overflight/ground measurement program as part of next spring's severe storm observational program seems appropriate.

C. Studies of cloud-to-ground lightning

We propose to broaden research on severe storms to include a comprehensive study of CG flashes. This research would entail analysis of CG statistics for a large number of both nonsevere and severe storms out to >200 km using a system for locating CG strike points. Such parameters as CG flash rates, duration of CG activity, temporal variation, areal extent affected, electric fields, number of return strokes, and peak currents would be examined. For a smaller number of storms within the NSSL VHF mapping and dual-Doppler area, more complete information on lightning activity, storm dynamics, etc., would enhance the usefulness of the larger data set by providing details, e.g., variation of IC to CG ratio, CG activity versus storm dynamics, etc. A study of this type is important to future interpretation of satellite observations of lightning and ground truth.

TITLE: SEVERE STORM ELECTRICITY — STORM INTERCEPT

RESEARCH INVESTIGATORS:

Dr. Roy T. Arnold, UNIVERSITY OF MISSISSIPPI,
University, MS 38677, (601)232-7046.

Dr. W. David Rust, NOAA/NSSL,
Norman, OK 73069, (405)360-3620,
FTS 736-4916.

SIGNIFICANT ACCOMPLISHMENTS FY-80:

The mobile laboratory was equipped in early April to record:

1. Electric field changes on two slow antennas and one fast antenna.
2. Electric field strength and corona current.
3. 3 MHz spherics at 6, 12, 24, and 48 km ranges (only two ranges are recorded at any one time).
4. Optical transients.
5. Sounds of thunder and tornadoes.
6. Lightning and other storm features with television, 35 mm slides, and Super 8 and 16 mm movies.

Because full monetary support was not received until 24 April, the S-band radiometry experiment has not been implemented.

For the period 2 April-31 May, the intercept team went out on 17 days and ranged over six states. On five intercept days there were no severe storms within tracking range, and on three other days there were no storms at all. We have successfully intercepted severe storms on 50% of days out.

On three occasions the intercept team tracked storms which produced tornadoes within range of single Doppler radar surveillance. A fourth storm perhaps produced a tornado which was recorded on video.

Storm intercept operated in support of the U2 overflight on 15 May, but the line of storms apparently produced no lightning while the U2 was over the area. On 20 May, Intercept was prepared to provide ground truth for a U2 overflight which later was cancelled. Cancellation was unfortunate since the storms within the dual Doppler area were prodigiously producing lightning.

On at least two occasions, CG flahses from the anvil of severe storms were documented clearly. At great distances from the (storm) tower, all of the flashes appear to have transferred positive charge to ground. Near, but outside of the main convective tower, most CG flashes appear to transfer negative charge to ground.

A mesocyclonic storm on 30 April was tracked throughout most of its life cycle. Over a portion of its development, it was tracked by single Doppler radar.

On various occasions, the mobile laboratory has provided ground truth for observations conducted from fixed base at NSSL.

CURRENT FOCUS OF RESEARCH WORK:

We are currently engaged in field operations. Our principal efforts during the remaining month of field work will be to:

1) track storms within the single Doppler area (250 km maximum range ).

2) collect data from a fixed point within both the lightning discharge mapping and Doppler areas and serve as a second station both for electric field change measurements and ground truth observations.

3) attempt to implement an S-band radiometry experiment.

4) continue data reduction and analysis.

PLANS for FY-81

We are now in a position to evaluate the scientific merits of storm intercept. During the 1980 operational season our data acquisition has been so successful that mobile field oprations will remain an important part of the UM/NSSL collaboration. However, data analysis will continue to grow in emphasis as we continue into FY-81.

# Lightning Characteristics and Its Relationship to Storm Structure

William L. Taylor
National Severe Storms Laboratory
1313 Halley Circle, Norman, OK 73069
(405/360-3620, FTS 736-4916)

## Significant Accomplishments for FY-80

Relating lightning location and other storm electricity parameters with storm reflectivity and internal wind structure is our major effort within the Storm Electricity Group at the National Severe Storms Laboratory. Definitive results require exceptionally good data obtained simultaneously from the dual VHF mapping, from an assortment of other storm electricity sensors, and from NSSL's dual 10 cm Doppler radars. Most lightning activity observed by the VHF mapping technique originates from discharge processes within the cloud and only a few impulses are observed from return stroke channels.

Results obtained this year include the following. The gross features of a discharge can be identified and tracked through the storm. The fine detail and interrrelationships of impulse sources are not clearly revealed, although impulses are accepted at rates to 16,000 per second. Lightning seems to progress along multiple branches in a wide front, but with occasional retrograde movement of VHF sources appearing back within previous electrically active regions suggestive of a recoil streamer mechanism. Lightning is closely associated with regions of high radar reflectivity, but avoids central cores of highest reflectivity. In storms containing mesocyclones or shear in the horizontal wind, lightning initiation occurs near these regions. The analysis of 63 discharges in one Oklahoma storm revealed the mean values of initiation height and discharge center height for cloud-to-ground discharges were 1.5 km lower than the corresponding parameters for intracloud discharges. The in-cloud progression speed of intracloud discharges was found to be about 20 percent slower, and yet the discharge extended horizontally almost twice as far, relative to the in-cloud progression speed of cloud-to-ground discharges.

## Current Focus of Research Work

We are presently engaged in our observational operations during the spring thunderstorm season in Oklahoma. Analysis of previously obtained data continues, and we are in the process of completing several papers. Data already collected this spring are in the process of being archived and checked for quality.

## Plans for FY 81

We plan to continue developing new techniques and expanding the data base to address some of the fundamental questions concerning the role lightning plays in the genesis, maintenance, and dissipation of severe and nonsevere storms. We will continue to analyze data simultaneously obtained from our many severe storm sensors. Through our efforts at NSSL in the areas of lightning location mapping, the characterization of lightning parameters, and the determination of relationships in the co-evolving fields of wind, precipitation and lightning, we will help NASA develop techniques that will assist the meteorological community in forecasting, detecting, tracking and warning of weather hazards through the use of lightning observations.

Recommendation for New Research

It is recommended that NASA examine the feasibility of utilizing ELF signals from lightning to detect cloud-to-ground strokes. A hybrid system using ground-based ELF observations and satellite optical (and other sensors) responses to detect and locate lightning strokes to ground would overcome many of the serious problems attached to other techniques.

We visualize a minimum effort would include ELF instrumentation design and testing, observations of ELF signals from known cloud-to-ground lightning, and data analysis with conclusions and recommendations. Existing systems at NSSL are uniquely combined for supplying the required lightning ground truth coupled with storm dynamics and structure. At least one site located about 1000 km from NSSL would be required to observe the ELF radiation field. Huntsville, Alabama, would be the logical, minimum-effort location for this site since the NASA timing and recording facilities could be utilized for obtaining ELF data from Oklahoma storms. One or more additional remote sites would guarantee an adequate data base for determining the detectability of cloud-to-ground strokes by an ELF technique.

**Title:** Storm Severity Detection (RF)

**Research Investigator(s) Involved:**

Dr. R. L. Johnson
Mr. M. L. Bushman
Electromagnetics Division
Southwest Research Institute
6220 Culebra Road
San Antonio, Texas 78284
(512) 684-5111

Significant Accomplishments FY-80:

During the period from 1 April 1979 to 1 September 1979, seventy one thunderstorm days were detected by sferic activity and monitored over an observation span of 526 hours. Sferic bursts are directionally resolved using a computer instrumented crossed baseline phase interferometer operating at 2 MHz with a 2.7 kHz bandwidth. Software was developed to provide automatic data acquisition without an operator in attendance. The system detects a thunderstorm in progress when sferic activity exceeds an empirically predetermined noise threshold and automatically logs azimuthally resolved sferic events to disc files. The following results have been obtained in the analysis of the 1979 data: (1) the data exhibit the first known capability for multistate regional severe storm discrimination using directionally resolved sferic burst counts. Simultaneous observation of two or more storm systems on a multistate regional basis has yielded real-time detection and discrimination of severe meteorological activity. (2) The phase linear interferometer is capable of severe storm discrimination and tracking to ranges of 2000 km, a factor of 2:1 greater than had been observed in earlier work. (3) The extended range capability permits observation of phase linear sferics from oceanic storm systems. This area of investigation has not previously been undertaken at this laboratory.

Current Focus of Research Work:

This program is directed toward determining whether or not HF sferic activity can be used routinely to discriminate meteorologically severe cells from non-severe cells. The HF detection frequency is chosen for long range detection and tracking of meteorologically intense storm cells. Work is in progress to analyze the data acquired in 1979 and extend data acquisition in 1980 to assess probability of failure to alarm, false alarm, and alarm reliability of severe storm detection based on phase linear, directionally resolved sferic burst counts. Also an assessment will be made to determine the capability of phase linear electrical activity to provide a short-term forecast of impending severe meteorological intensity. Work is in progress to review existing sferic data for elevation angle capability for gross range estimation.

**Plans for FY-81:**

1. Since RF lightning observations from space must necessarily be conducted above the critical frequency of the ionosphere, data acquisition will be made at frequencies near the critical frequency as predicted by virtual incidence soundings. Measurements will be conducted vertical to determine whether or not the storm severity indications observed at 2 MHz are also valid at higher frequencies.

2. Concentrate on a systematic surveillance of the Gulf of Mexico region for oceanic thunderstorms and tropical cyclones. The primary objective will be to determine whether or not sferic activity is also diagnostic of meteorological intensity in oceanic storms as well as inland storms.

Recommendations for New Research:

Based upon the results obtained to date, the following are recommended initiatives:

1. Develop a geodetic mapping algorithm to display satellite and directional sferic count data on a tracking chart (instead of the existing oblique spheroid view) for automatic real-time data analysis.

2. Deploy multiple phase linear sferic sensors to permit triangulation and storm scale location based on phase linear electrical phenomena associated with severe meteorological activity.

3. Continue effort to study oceanic electrical storm data. This area of research, in particular, could exploit multiple station triangulation of sferic data.

# REMOTE OBSERVATIONS OF LIGHTNING AND SEVERE STORMS

Richard E. Orville

Department of Atmospheric Science
State University of New York at Albany
Albany, New York 12222

## Defense Meteorological Satellite Program

Under a cooperative program with the University of Wisconsin's Space Science and Engineering Center, we are receiving monthly maps of the midnight lightning recorded by the DMSP satellites. Maps for September, October, and November have been received, digitized, and plotted for our study. The location of over 2,000 flashes per month show interesting correlations with the general circulation features and raise questions about the frequency of lightning over the oceans. A paper on this work has been accepted for the International Cloud Physics Conference in Clermont-Ferrand, France, July 1980. Our study will continue until we have the midnight lightning distribution for twelve consecutive months. This will provide us with the global distribution of approximately 25,000 flashes, enabling us to observe the seasonal variations, land-ocean ratio, and flash rates.

## Spectroscopic Studies

Data analyzed to date show no significant difference between intracloud spectra and cloud-to-ground spectra for 150 msec time resolution in the 400-700 nanometer region. Studies this summer will concentrate on the 600-900 nanometer region. An absolute calibration system tied to an NBS standard will be used for the first time to calibrate our data.

## Simultaneous Lightning Location and Satellite Data Displays

A cooperative study has been initiated to display simultaneously ground strike lightning on satellite visible and IR imagery. Lightning data have been supplied by Mike Maier of NOAA, Miami, Florida. Other scientists working on this program include Fred Mosher, University of Wisconsin, and David Rust, NSSL, Norman, Oklahoma. We have successfully initiated our study on April 10, 1979, data and are extending our study to a non-tornadic storm of May 20, 1979. Radar data from the NSSL Doppler system have recently been received and will be incorporated into our study.

U-2 Aircraft Observations of Severe Storms

In a cooperative program with O. H. Vaughan, M. Brook, and B. Vonnegut, U-2 overflights of thunderstorms have recently been completed. The most successful flight occurred on the evening of May 16. Slow electric field, near infrared, spectroscopic, and photographic data were obtained on an active thunderstorm to the northwest of Little Rock, Arkansas. Numerous flashes were recorded by the U-2 plane and a few are apparently correlated with data obtained by the lightning location system operated at NSSL, Norman, Oklahoma.

**TITLE:** Video Observations of Lightning Spectra

**RESEARCH INVESTIGATORS:** K. Stuart Clifton
ES64
Marshall Space Flight Center
(205) 453-2305

C. Kelly Hill
ES84
Marshall Space Flight Center
(205) 453-2570

**SIGNIFICANT ACCOMPLISHMENTS FY80:**

During the past year the results obtained from the 1979 expedition to Socorro, New Mexico, as part ot the Thunderstorm Research International Program (TRIP), have been reduced. The purpose of this research was to evaluate a low-light-level television system for use in obtaining spectral signatures of lightning. The system used for these observations was a low-light-level SEC vidicon equipped with a single-stage intensifier. The camera used an f/0.75 105-mm lens and a full-aperture 300 line/mm grating blazed to 5000 Å.

Nearly 1400 lightning flashes were detected throughout 7 hours of observations. As a by-product of the spectral research, the number of strokes per flash of observed channels, as well as interstroke intervals and flash durations were measured for storms ranging from 50-200 km away from the observation site. The flash frequency was also obtained for a severe storm system at a distance of 320 km. Comparisons of these data were made with similar studies conducted previously using television and photographic means. These results were submitted for publication in the Bulletin of the American Meteorological Society.

Spectra were obtained for flashes to an estimated distance of over 200 km. One hundred and seventeen spectra were recorded during the Socorro observations, 36 of which, proved to be of relatively good quality. A considerable amount of time was spent in developing the techniques for the analysis of the lightning spectra. A technique was developed whereby selected video frames were digitized and stored on digital tape. The tapes were then read into the Marshall Space Flight Center (MSFC) Image Data Processing System (IDAPS) where the relative image intensity versus the position in the video image could be measured. Printouts of data obtained from IDAPS were examined from which selected portions were input to a calculator/plotter, and smoothed spectral scans were plotted. Spectral features could be identified from the resulting plots. Eight spectral features have been readily identified and two additional features have been tentatively identified.

In addition to the spectral identifications, the data showed the following characteristics: (1) on nearby spectra, the H$\alpha$ line was not necessairly the brightest feature as often shown in photographic data. Current efforts are being undertaken to compare the spectral responses of video and other (photographic) systems. (2) The data showed a strong suppression of the blue end of the spectrum caused by Rayleigh scattering of distant channels. The relationship between distance and the amount of cutoff is currently being investigated; (3) In five cases the field can line "intercepted" a lightning stroke as it occurred, such that only the bottom portion of the channel was apparent. All of these events were distant, however, and a step leader was not observed. With either increased sensitivity or with continued observations of nearby lightning, the video system should prove to be an excellent detector of step leaders. One spectrum of a potential step leader was obtained. (4) One apparent intracloud event was recorded. Techniques are currently being developed to record optimally intracloud channels.

CURRENT FOCUS OF RESEARCH WORK:

In addition to the current research mentioned above, attempts are being made to reduce dramatically the time and effort required to obtain a spectral scan of the data. A desktop computer is presently being interfaced with the digital image memory and an X-Y plotter for high speed examination of the data. An intensified SIT vidicon camera is currently being used at MSFC to record both distant and nearby storms. The camera will also operate in both day-or nighttime and should prove a valuable step leader research tool. Both airborne and ground-based observations are planned for August, 1980 in the vicinity of Socorro, New Mexico. Emphasis will be placed on intracloud activity as well as comparative results obtained simultaneously from above as well as below the cloud levels.

PLANS FOR FY81:

FY81 will see a continuation of these efforts beyond the evaluative level. Attempts will be made to enhance existing data and to improve observational and analysis techniques. Reports will be issued on a regular basis. In addition to the intracloud and cloud-to-ground ligtning studies, the video cameras wimm emphafize step leader research and the detectability of major spectral lines in the 7000 - 8500 Å region.

**Title:** PBE Lightning Data Analysis

**Research Investigator:** Bob Turman
Division 4252
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185
(Formerly - USAF Academy, CO.)

**Significant Accomplishments FY-80:**

1. The detection probability for cloud-ground strokes has been estimated by combining source power distribution data (Turman, 1978) with transmission statistics for cumulonimbus clouds (Turman and Cook, 1980). The results predict that 50% of all cloud-ground strokes can be detected by a satellite sensor with a threshold of $2x10^8$ watts, and 85% can be detected at a threshold of $1x10^7$ watts.

2. The PBE detection fraction has been evaluated in three different ways - with three different results! But from these calculations, it seems that PBE detects 2-8% of the flashes in its field of view.

a. PBE trigger density, averaged over $10^o$ bins, has been compared to average lightning flash density values in the literature. The result is a detection fraction of 0.01 - 0.03.

b. Direction finder (DF) data from SESAME 79 have been collected by Mike Maier for use in ground-truth measurements. Comparison of the DF ground-flash rate with the PBE trigger rate (for two days) gives a detection fraction of 0.07 - 0.08.

c. The total flash rate (cloud-cloud plus cloud-ground) can be estimated from the cloud-ground flash rate measured by DF. Comparing this rate with the PBE trigger rate gives a total detection fraction of 0.06 (again based on data from two days).

3. Another aspect of this research is a study of lightning activity associated with tornadoes (Turman, et al, 1979). Between August 1977 and December 1978, PBE observed 11 tornadic storm complexes within 30 minutes of tornado touchdown. Trigger rates for these severe storms were compared with trigger rates for non-tornadic storms, with the result that the tornadic storm mean rate was at least 1.9 standard deviations above the non-tornadic storm mean rate. It appears that the increased lightning activity precedes tornado touchdown by at least 30 minutes.

**Current Focus of Research Work:**

1. Optical properties of lightning signals observed from space.

2. Tornado detection with lightning sensors.

**Plans for FY 81:**

1. The cloud transmission project will be continued at the Air Force Academy, under the direction of Captain Larry Freeman. Operation of the experiment this summer should provide improved Cb transmission statistics. These statistics will be used in further study of the cloud-ground stroke detection probability.

2. The SESAME 79 and SESAME 80 ground-truth data will be analyzed as discussed in the first section. When this analysis is complete, we should have a better estimate of the PBE detection fraction. This fraction will then allow us to calculate absolute values for global lightning flash distributions.

3. Tornado data from 1979 are now being processed. Completion of this analysis should more than double the size of our tornado-lightning correlation data base, thus improving the statistical significance of the correlation.

**References:**


Turman, B. N., Analysis of lightning data from the DMSP satellite, J. Geophys. Res, 83, 5019, 1978.

Turman, B. N., R. J. Tettelbach and K. B. Stevens, The Possibility of Severe Storm Detection with Satellite Lightning Sensors, presented at the 11th Conference on Severe Local Storms, American Meteorological Society, Kansas City, MO, October 1979.

Turman, B. N., and J. W. Cook III, Optical Transmission Characteristics of Clouds. A Preliminary Report, Paper presented at the Satellite Working Group Meeting, Patrick AFB, FL, March 1980.

**Title: Correlation of Satellite Lightning Observations with Ground-Based Lightning Experiments.**

**Research Investigator:** B.C. Edgar
Aerospace Corporation
Box 92957
Los Angeles, CA 90009
213-648-5261

**Significant Accomplishments FY-80:**

1. Organized and coordinated satellite passes over various ground-based lightning experiments in Oklahoma (April-May), Tampa (July-August), Miami (June-August), New Mexico (August), and KSC (May).

2. Completion of paper "Global lightning distributions at dawn and dusk" and submittal to JGR.

3. Acceptance of paper for International Atmospheric Electricity Conference. The paper deals with the global distribution and the causal conditions for superbolts.

**Current Focus of Research:**

1. Organization and analysis of ground-truth data from 1979.

2. Coordination of 1980 ground truth tests.

**Plans for FY 81:**

1. Analysis of ground truth data from SESAME-80 and BLM Western U.S. network.

2. Further analysis of ground-truth data from 1979.

**Recommendations for New Research:**

1. Reduction of continuous PBE satellite data (Sept. 1978 - Oct. 1980) for global distributions of lightning in intervals of 1-2 weeks.

**Title:** Solar Influence on Terrestrial Weather and Global Lightning Patterns via Cosmic Ray Modulations

**Research Investigator:** Dr. John T. A. Ely
Space Sciences Division
Geophysics Program
University of Washington, FM-15
Seattle, WA 98195

**Significant Accomplishments:**

1. To determine atmospheric conductivity (primarily in the 10 to 50 km altitude region) and correlate it with weather, lightning, magnetic storms, and other processes of interest (including SCATHA), a particle telescope was launched into a low-altitude, polar, noon-midnight orbit on Satellite S3-4 in 1978. This instrument made precise and frequent latitude surveys of the galactic cosmic ray flux at and above 1 GV rigidity (the 1 GV particles are the principal cause of ionization at 10 km altitude) for about 600 orbits in 180 days.

2. Presented a theory (summarized on pages A-25, -26 of NASA Conference Publication 2098) explaining solar activity influence on the weather via various short and long term modulations of the 1 GV cosmic rays altering atmospheric ionization in the 10 km region and a mechanism by which this effect influences the amount of high latitude cirro-stratus clouds.

3. Submitted a paper to Planetary and Space Science in April 1980 on the theory of factors influencing lightning incidence predicting six global patterns, two of which have been observed.

**Current Focus and Plans for FY-81:**

1. Analyze the satellite data from our experiment (SFEX) as described above and combined with the analysis of the data of another experiment (SRE-TRE) on the same vehicle to look for additional global lightning patterns (in particular, an intermittent north-south asymmetry) as further tests of the theory.

2. Submit the sun-weather effect theory to Science.

3. Complete a theory explaining equatorial electrojet oscillations and linking them to SCATHA events.

**Recommendations for New Research:**

The SFEX type low-altitude polar cosmic ray surveys ($\geq$ 1 GV) should be done continuously over two solar cycles to determine the magnitude of the 22 year variation predicted by the theory and visible in Stringfellow's high latitude (England) lightning observations over four solar cycles.

## Research into Radiation and Scattering of Ionized Lightning Channels

Thomas H. Shumpert
Martial A. Honnell
Electrical Engineering
Auburn University, Alabama 36849
(205) 826-4330

### FY-80 Accomplishments

Visited NSSL lightning detection facilities and identified potential frequency regimes where additional measured data is needed. Discussions with David Rust and Bill Taylor provided timely direction in the development of measurement equipment at Auburn - December 1979

Visited lightning detection facilities at Southwest Research Institute. Dick Johnson reviewed measurement equipment and procedures utilized in their efforts - December 1979

Visited with John Herman of Radio Sciences Company. Discussions focused on the noise environment (both natural and man-made) in the UHF, SHF, and EHF regions of the RF spectrum. Windows of potentially low ambient noise were identified for areas for high concentration in Auburn's data collection efforts - February 1980

Continued development of and improvement in data collection facilities and capabilities. These include the addition and installation of a 10'x10'x8' Lindgren double-shielded AC filtered screen room; a Drake R-7/DR-7 Receiver covering the frequency range from 10kHz to 30 MHz; a 5' diameter parabolic dish antenna with a dual-polarized log-periodic broadband feed to cover 1 to 10 GHz; a Panasonic Portable Video Camera, Recorder, and Monitor; and a Z-80 based micro-computer system with twin floppy disk drives for measurement documentation and management.

Secured large-scale system program from RADC for modeling of VHF and UHF emissions from lightning channels.

### Current Focus of Research and Plans for FY-81

Daily operation of data collection facility with additional improvements in instrumentation as planned or needed. This operation will include monitoring, recording, cataloguing, and analyzing electromagnetic (RF) signals produced by lightning with emphasis in the upper VHF, UHF, and

SHF portions of the electromagnetic spectrum. Spectral and temporal characteristics as well as polarization differences will be included.

Improvements planned for the measurement facility include the addition of a multichannel (7) wideband recorder system; two high-speed cameras coupled to high-frequency oscilloscopes; and a Tektronix 7912 transient digitizer (much of this equipment available from other in-house research efforts currently underway)

Continued implementation and development of existing computer models for predicting the emission and scatter fields from lightning channels.

## Recommendations for New Research

Accumulate (with ready availability to all investigators) an extensive data base of actual recorded lightning emissions including sensor-system characteristics

Repeated analysis of data base for common data characteristics distinguishing stroke type (intracloud or cloud-to-ground), storm type/severity (rain, hail, tornadic, etc.), or other definitive parameters

Establish one or more synchronous platform RF sensors with different threshold levels for determining baseline signal strengths at synchronous altitude

Support all (as many as possible) space-based observations with ground truth measurements

Improve existing models and generate new models for simulating lightning-produced emissions

Seriously investigate "active" vs "passive" sensor/detection systems

Title: Electric Field Mill Development

Research Investigators: R. V. Anderson, PI
John C. Willett
Code 4325
Naval Research Laboratory
Washington, D. C. 20375
202-767-3350

Significant Accomplishments:

An extensive series of laboratory tests of Volta potentials on possible field mill construction materials has been conducted. Three test plates of each of nine materials were prepared and chemically cleaned. Their potential differences relative to one another and between samples of the same material were measured by observing the applied potential difference required to yield zero current in a test environment with artificially high ionization levels. The plates were then exposed to weathering for several days, measured, re-cleaned, and re-measured. This cycle was then repeated several times in an attempt to detect any long term secular variations. Suitability criteria then applied included change with weathering, consistency, and durability of the surface. At present only iridite finished aluminum alloy and 18-8 stainless steel appear to be suitable; the tests continue to effect a decision.

The sources of error and noise in field mill systems have been analyzed on the bases of theoretical considerations and operational experience with mills of both shutter and cylindrical design. Possible error generation mechanisms have been identified and appropriate reactions to each have been proposed. A test bed for use in the NRL electrostatic test facility has been fabricated with which it will be possible to evaluate these presumed error mechanisms and proposed remedies for their validity, pertinence, and efficacy.

Current Focus of Research Work:

The implementation and utilization of the test bed facility constitutes a major fraction of the current effort. It will be used to obtain answers to questions of mechanical design, sensor exposure, geometric compensation for asymmetries, signal coupling between rotating and stationary elements, analog vs. digital circuitry, and achievement of appropriate dynamic range. It is obvious that many trade-offs will be encountered such as between physical size and signal amplitude, between circuit simplicity and enhanced dynamic range, and between circuit configurations which enhance performance and those which facilitate operational convenience. Experiments designed to isolate specific trade-offs will resolve these questions.

**Plans for FY-81:**

The current work with the test facility outlined above will be completed. An initial prototype field mill will be fabricated on the basis of the test results, and preliminary flight tests will be conducted. Test results will be incorporated into designs for an operational field mill.

**Recommendations for New Research:**

Development of an operational mill and its incorporation into an aircraft system for the measurement of the three component vector field is an obvious sequel to the efforts herein described. Such a system would be configured to be operable by observers without specialized training or experience, and it would be designed for reliability in operation and ease of repair.

TITLE: U-2/NOSL GROUND TRUTH STUDIES

RESEARCH INVESTIGATORS: M. Brook
New Mexico Tech
Socorro, New Mexico 87801
505-835-5611

R. E. Orville
State Univ. of New York at Albany
Albany, New York 12222
518-457-3985

O. H. Vaughan, Jr.
ES83/MSFC, AL 35812
205-453-5218

B. Vonnegut
State Univ. of New York at Albany
Albany, New York 12222
518-457-4607

SIGNIGICANT ACCOMPLISHMENTS:

Data has been analyzed and published relating photo-optical measurements made from a U-2 aircraft above a New Mexican thunderstorm to similar photo-optical measurements, radio frequency electromagnetic radiation, and field changes obtained from a slow antenna. These results show excellent correlation between the optical observations above and below the cloud. The optical signature of the cloud-to-ground lightning discharge could be clearly detected from above through the intervening thunderstorm cloud.

For studies in 1980 the measurements package in the U-2 aircraft has been modified to include a slow antenna field measuring device and a spectrometer made by placing a grating in front of a NASA CCD line scan camera. The photographic system, which consisted of a single 9 X 9 format aerial camera, which was used in the 1979 New Mexico operation, has been exchanged for a 3 camera system employing 70 mm film. This camera system is so arranged that it can be operated in the open-shutter mode at night to provide photographs of lightning channels and cloud structures illuminated by lightning.

Almost an hour's observations were made at night over a thunderstorm with a top at about 40,000 feet near Ft. Smith, Arkansas. Preliminary analysis of the data shows that over 100 lightning flashes were recorded on the photo-electric optical recorder on the slow antenna apparatus and on the spectrometer. Photographs were also obtained with the open-shutter equipment looking down on the cloud structure in which several lightning channels could be seen. Preliminary analysis confirms that cloud-to-ground discharges are detectable with the optical equipment despite the thick layer of cloud above them.

CURRENT FOCUS OF RESEARCH WORK:

The primary effort will be devoted to analysis of the data obtained over the nocturnal thunderstorm. During the month of August it is planned to make further U-2 flights in order to obtain ground truth data on thunderstorms in the vicinity of Socorro, New Mexico, where ground equipment will be operated to obtain field change, photo-optical data, and RF measurements.

PLANS FOR FY 81:

It is planned to extend the instrumentation of the U-2 aircraft to obtain additional information on the lightning and thunderstorm by adding appartus to detect and record radio frequency electromagnetic radiation and, if it can be arranged, to make measurements of atmospheric electrical conductivity above the cloud tops. Extensive ground truth experiments will be carried out during FY81 to obtain more detailed comparison of the relationship between signals observed from above and those observed from below. These flights will be coordinated with ground observations from well instrumented laboratories and instrumented trucks both at the NSSL in Norman, Oklahoma, and at the Langmuir Laboratory on Mt. Baldy near Socorro, New Mexico.

RECOMMENDATIONS FOR NEW RESEARCH:

It is desirable that investigations be carried out to perfect instrumentation that can be used to make studies of lightning and cloud electrification from orbiting and geostationary satellites. Plans are under way to compare the advantages and disavantages of using video tape equipment and recorders in place of the conventional motion picture cameras presently being used. At the present time, the data being obtained with the photo-optical system and the NOSL equipment are severely limited by the small bandwidth of the tape recording equipment. It appears that it may be desirable to utilize a system with far greater data handling ability that can provide frequency response of a megahertz or higher.

## NIGHTTIME AND DAYTIME OPTICAL SURVEY OF THUNDERSTORM LIGHTNING (NOSL)

**RESEARCH INVESTIGATORS:**

Principal Investigator - Dr. B. Vonnegut
Department of Atmospheric Science, ES323
State University of New York at Albany
1400 Washington Ave.
Albany, N.Y. 12222

Co-Investigator - Mr. O. H. Vaughan, Jr.
Atmospheric Sciences Division
Space Sciences Laboratory
Marshall Space Flight Center, AL

Co-Investigator - Dr. Marx Brook
R&D Division
New Mexico Institute of Minning & Technology
Socorro, N. M.

SIGNIFICANT ACCOMPLISHMENTS FY-80:

o Continued development of NOSL Hardware for Shuttle Flight Experiment

o Developed required instrumentation for ground testing, U-2 Flight hardware, and data analysis techniques.

o Collected data on lightning storms in May 1980 at NSSL, Norman, Oklahoma using NOSL training hardware.

o U-2 Thunderstorm Overflight Spring Program (TOP) was completed and data was collected from 4 on-board sensors and ground truth instrumentation.

o Technical Papers: (1) NASA TMS 78261 "Nighttime/Daytime Optical Survey of Lightning and Convective Phenomena Experiment" (NOSL) B. Vonnegut, O. H. Vaughan, Jr. and Marx Brook, February 1980.

(2) Geophysical Research Letters "Simultaneous observations of lightning radiations from above and below clouds, Marx Brook, Richard Tennis, Charley Rhodes, Paul Krehbiel, Bernard Vonnegut and O. H. Vaughan, Jr.

PLANS FOR 81

o Continue work on all required interfaces between MSFC and JSC for NOSL flight experiment and training of Shuttle crew members.

o More U-2 flights are planned for Spring 81 and Summer 81 for collecting lightning signatures from onboard and ground truth instrumentation.

o Continued development for an improved NOSL experiment for reflight on Shuttle.

RECOMMENDATIONS FOR NEW RESEARCH

o Compare ground and U-2 observations using cine - cameras, optical NOSL, and video camera systems and RF techniques for collecting lightning signatures.

o Develop more advanced data analysis techniques for NOSL using computers.

o Develop additional airborne sensors and electronics packages for use in Aircraft - Thunderstorm Overflight Programs.

# Lightning Mapper — Science and Applications Team

Arthur A. Few, Jr.
Department of Space Physics
Rice University
Houston, Texas 77001

The annual lightning damage cost (fire, aircraft, livestock, forest fires, power transmission) has been estimated at more than 100 million dollars. In addition to these losses, the electrical power industry estimates that 10% of the capital equipment costs of power transmission is associated with lightning protection. Perhaps the greatest cost is in human lives; about 150 Americans are killed each year and another 250 injured by lightning. We cannot control or prevent lightning, but we are in an excellent position, technologically, to provide real-time lightning location, tracking, and warning.

The objective of the Science and Applications Team is (1) to identify all of the potential users of lightning information, (2) to describe the information that they want about lightning, (3) to determine the data that is required to provide the user information, and (4) to translate these data requirements to sensor requirements by interactions with the R F and Optical Sensor Teams. At the completion of this cooperative team activity we will have identified the subject of all lightning data requirements that either require or are best suited to observation from satellite.

Our users have diverse needs and requirements but they can be divided into user groups based upon certain pivotal requirements. One point of division is on timeliness; some users (operations, forecasting, etc.) need real-time data, others (planning, climatology, etc.) require cumulative-data, while a third group (engineering, lightning protection design, etc.) is concerned with statistical data that has been thoroughly analyzed. A second major aspect to user grouping is related to coverage of the lightning observations. One user group (research, global operations, etc.) requires continuous global monitoring of lightning activity; a substantial number of users (forecasting, warnings, operations, etc.) need continuous observations of the continental United States or a subset thereof; a third group (research, storm tracking) are interested in a smaller pointable field of view with higher temporal and spatial resolution but do not necessarily need continuous full time operation.

At the next level of comparison of the user data needs we get into the details of their applications; here it becomes more difficult to define large user groups. For example, the forestry operations want location of only cloud-to-ground flashes with a precision of 250m at the point of strike, and they want to know if the flash contained continuing currents. By contrast, air traffic is interested in all lightning activity and the location of the volume containing the lightning activity.

Our task is to correlate the full spectrum of user requirements with satellite observational capabilities and find the applications and users that we can serve.

**Title:** Lightning R.F. Sensor Team

**Investigator:** E. Philip Krider
Institute of Atmospheric Physics
University of Arizona
Tucson, Arizona 85721

**Accomplishments (FY-80):**

1. About 30 scientists with research experience or interest in lig[illegible] R.F. detection were asked to suggest specific methods for detecting [illegible] locating lightning from space using a geosynchronous platform. Seve[illegible] critical unknowns were identified immediately:
   a. The absolute R.F. intensities radiated by various lightning processes, at frequencies which will penetrate the ionosphere, are small and are poorly known:
   b. The amplitude and time-behavior of the R.F. background on the surface of the earth is poorly known; and
   c. Criteria whereby the amplitudes and time patterns of R.F. could be used to determine the type of discharge, or other flash characteristics, are not rigorously established.

2. In spite of these difficulties, two possible satellite approaches were suggested:
   a. A noise receiver viewing the full disk of the earth could be used to simply count all R.F. transients above some minimum threshold. Subsequent calibrations by comparing the rates with ground-based sensors would provide area-averaged statistics.
   b. An array of radio interferometers viewing a large area disk could both detect and locate flashes.

3. There were also suggestions that a combination of satellite and ground-based technology would offer some unique advantages. A satellite could be a platform both to receive and process groung-based data, and to broadcast lightning locations back to Earth in an easy-to-understand format. The ground-based sensors could provide accurate strike locations and many of the physical characteristics of the flashes.

**Current Work:**

An experiment is presently underway to measure absolute lightning field amplitudes from DC to about 50 MHz. Lightning locations will be measured and an effort will be made to minimize the effects of ground-wave propagation. The absolute light intensity vs. time in the 0.4 to 1.1 $\mu$m region will also be measured in correlation with the lightning fields.

**Future Plans:**

After the summer measurements, we plan to analyze the results, and we will attempt to model, on a computer, the effects of clouds on the light signals produced by lightning. We will pay particular attention to the effects of multiple scattering on:

a. The light signal vs. time
b. The fraction of light which escapes the cloud tops
c. The dimensions of the cloud top illumination
d. Optical position errors produced by asymmetric scattering.

**Title:** Broad-area Optical Lightning Telescope System

**Research Investigator:**

William Wolfe
Optical Sciences Center
University of Arizona
Tucson, Arizona 85721
(602) 626-3034

**Significant Accomplishments (FY-80):**

Conceptual Design of Four Geosychronous Sensors

**Current Focus of Research Work:**

Refinement of designs leading to a prototype.

**Plans for FY-81:** Prototype design and construction

**Recommendations for New Research:**

Consideration of several simple satellite,aircraft and balloon sensors leading to getting information for the final system.

1. We have developed the conceptual designs for three sensors which determine the occurence and location of lightning strokes - over a 1000 x 1000 $km^2$ area, the continental US and the disc of the earth as seen from synchronous orbit (mappers). We have also carried out the conceptual design of a satellite polychromator which has about 250 spectral channels in the silicon band and a sample time of 0.1 ms. The first two of the mappers provide a probability of detection of 99% or more for a stroke which has $10^7$ watts or more above the clouds. The global system has a 70% probability. Ninety-five percent of the first return strokes are in excess of $10^7$ W. The system consists of a six-element lens, a 400 x 800 active-element silicon CCD with two equivalent memories. The CCD is sectioned into 10 columns of 80 x 400 elements to accomodate the 1 ms frame time. These ten parallel data streams are fed to two memories (for each of the ten). One memory contains the 80 x 400 pixels delayed by one frame time. These two frames are subtracted, pixel by pixel, to eliminate the background. The differences are fed to a two-sided thresholder, a buffer and a multiplexer. This serial data stream is then digitized. The information derived is then based on the number of digits required for the identification of a stroke and the stroke statistics. We estimate that 45 bits are needed for identification. Then for an average stroke rate over the US of $2.3 \times 10^{-7}$ $km^{-2}sec^{-1}$ one finds a data rate of about 100 bits/sec. Even if it is assumed that the US is completely covered by a severe storm, the data increases to only 20 $kbs^{-1}$. The optical system centers around the NI(1), 0.87 band as defined by a narrowband filter on

one surface of an optical element. The spatial resolution of the optical system is satisfactory, although the optics may be more complicated than necessary.

2. A new spectrometer concept has been developed, one which we call a polychromator. A predisperser or wideband filter is used in front of a diffraction grating. The grating in turn spreads the spectrum over a linear CCD or diode array of 256 elements. The array is sampled $10^4$ times a second. All data are stored in a memory, and can be integrated over either time or spectrum. Thus time-resolved data to 100 $\mu$s cells or spectral data resolved to about 30 Å. Both of these can be done with about $10^7$ W strokes. More intense strokes can be resolved proportionately in time and spectrum.

**Title: Noise and Interference Study for Satellite Lightning Sensor**

**Principal Investigator:** John R. Herman
Radio Sciences Company
624 Tulane Avenue
Melbourne, Florida 32901
telephone: (305) 723-7425

## Significant Accomplishments FY-80

Initiated investigations of characteristics of radio noise sources and the modifying propagation effects to establish expected RFI background at geosynchronous altitude.

Established bounds on scope and depth of current study. On basis of preliminary analysis, identified spectral regions offering potential operational advantages, but which require further collaborative study by the rf team before final selection. In frequency range 1-10 GHz, it appears that recent measurements of noise power radiated from lightning flashes exceed previous theoretical predictions by several dB, making this one of the candidate ranges. To avoid interfering signals, recommend operation in protected frequency bands (Table 1).

Prepared invited review paper "Noise Sources in Near-Space Spectrum Pollution" for presentation at International EMC Symposium in Wroclaw, Poland, September, 1980.

## Current Focus of Research Work

Currently working on relative importance and spatial distributions of man-made noise vis a vis natural noise preparatory to establishing expected rf lightning signature/noise ratios at geosynchronous height. Also, in process of establishing methods to account for radiation pattern and propagation effects on the apparent distribution of sources as observed from space.

Other noise characteristics being considered include the spectral signatures, amplitude and time statistics, polarization and waveforms. Propagation effects under consideration include absorption, refraction, scattering, dispersion, Faraday rotation, distance attenuation, and temporal/spatial variations. The possible effects of ionospheric scintillation on lightning signatures observed at satellite height are being investigated.

## Plans for FY-81

Refinement of transient noise and interference characteristics to provide for development of hardware or software techniques designed to minimize "false alarm" rate, and/or rejection of contaminated data.

Utilization of rf lightning and noise data from ongoing ground-based programs for frequencies especially above 100 MHz to refine the estimates of background noise and desired signal characteristics at satellite altitudes of interest.

Analysis of rf data from existing satellites to obtain in situ estimates of background noise and interference for comparison with projected results from extrapolated ground-based data.

## Recommendations for New Research

Investigate possible role of intermodulation processes as a determining factor in the spectral distribution of noise in space. For example, does intermodulation of transmitted signals on different frequencies take place to any significant extent in the (non-linear) ionosphere, whereby rf energy of the intermodulation products would show up in unexpected portions of the spectrum?

Compare ground-based rf lightning measurements with satellite optical measurements for "ground truth" assessments.

Consider the question of spurious local discharges due to spacecraft charging. Will they occur and what would be the interfering effects if they do?

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Table 1. Radio Frequency Protected Bands.

| | | | |
|---|---|---|---|
| 73.00 - 74.60 | MHz | 2.690 - 2.700 | GHz |
| 406.1 - 410.0 | MHz | 4.990 - 5.000 | GHz |
| 1400 - 1427 | MHz | 10.68 - 10.70 | GHz |
| 1660 - 1670 | MHz | 15.35 - 15.40 | GHz |

**TITLE: Optical Sensor Development Support**

**RESEARCH INVESTIGATORS INVOLVED:**

Thomas Barnes, EC35, MSFC
205-453-1574

**SIGNIFICANT ACCOMPLISHMENTS FY-80:**

The inhouse optical sensor development support provides the needed flexibility to evaluate representative sensor systems and techniques as they are defined by the Feasibility Study.

Initial accomplishments in FY-80 were related to activation of local facilities for spring and summer lightning observations. The facilities are located on the 10th floor of building 4476. Video tape recordings have been made with standard vidicons, silicon target vidicons and CCD arrays. Lightning sensors are being employed to automatically turn the station on when lightning activity occurs.

Representative state-of-the-art sensors and associated components have been ordered to carry out sensor evaluation and various signal "extraction" techniques. These included both area and linear solid state arrays, CCD camera systems, integrated photo-diode/amplifier packages, CCD analog shift registers, optical bandpass filters and a variety of amplifiers, comparators, timers, multiplexers, etc. Due to long lead times, some of this hardware is just arriving and most items are not due before summer.

Recently, "cloud top" photography analysis was begun in response to the feasibility study. Several satellite photographs have been obtained and other sources are being investigated along with a literature search. It is desired to arrive at accurate cloud top brightness levels and variations within typical sensor revolution areas.

Work has continued in familiarization and use of the Gamma Scientific scanning spectral radiometer system. The system provides the capability to print-out and plot optical system parameters relative to sensors, filters, standard source calibration, etc.

Current focus of work - Techniques for evaluating sensors and signal processing are being firmed up. An aircraft flight experiment is being designed to carry out accurate cloud top intensity measurements utilizing various optical bandpass filters.

A two-camera system is being designed for determining location and range of lightning events. This system will be used to correlate simultaneous optical and RF observations.

**Title:** R. F. Lightning Measurements

**Research Investigator:** Warren Harper
NASA - MSFC, EC31
(205) 453-4621

**Progress:**

1. An R. F. Lightning measurement program being implemented at the Marshall Space Flight Center includes measurements in the VHF/UHF and microwave portions of the electromagnetic spectrum. Two measurement facilities are being prepared for performing intensity and polarization measurements in the 200-500 mHz band and in the 2-5 gHz band. Waveforms will be recorded by use of a combination of magnetic tape and solid-state memory devices. The two measurement sites will be located 2.2 kilometers apart on a line that is approximately perpendicular to the direction from which most thunderstorms approach the area. Use of direction-finding equipment will enable location determination of the lightning discharge to be made.

2. The measurement program is being conducted to expand the existing data base, especially in those frquency bands that are relatively unaffected by the ionosphere, to obtain simultaneous measurements at widely-separated frequencies, to obtain complementary waveform data from short-duration, high temporal resolution and long-duration, low-resolution records. Future goals are development of improved measurement and recording systems, development of theoretical models and improvement of data processing methods.

# THE PHYSICS OF RF RADIATION FROM LIGHTNING

**RESEARCH INVESTIGATOR:**

D. M. Le Vine
NASA/Goddard Space Flight Center
Microwave Sensor Branch/Code 946
Greenbelt, Maryland 20771
301-344-8059

**ACCOMPLISHMENTS:**

Significant questions remain concerning both the mechanisms responsible for radiation at radio frequencies and also the detailed structure (e.g., temporal statistics and peak power) of this radiation. This is especially true at frequencies suitable for monitoring from space. The objective of the research program at the Goddard Space Flight Center has been to resolve questions concerning the physics of the radiation and to provide those characteristics of the radiation needed in the development of techniques to monitor severe storms and associated electrical processes. Notable milestones in FY80 have been:

o <u>Sources of the Strongest RF Radiation</u>: Experiments originally performed in Florida during the Thunderstorm Research Project (TRIP) were repeated at NASA/Wallops Flight Center (WFC) last summer (1979). Both experiments indicate an especially fast intracloud event as the source of the strongest radiation from the flash in the frequency range 3-300 MHz. Theory to support these experiments has been developed and the details have been accepted for publication in the Journal of Geophysical Research.

o <u>Spectrum of Radiation from Return Strokes</u>: Radiation from first return strokes collected during TRIP-78 in Florida has been processed and spectra produced to frequencies near 1 MHz. The experiments confirm a theory developed at Goddard for the spectral shape, and suggest an important role for channel tortuousity at frequencies above about 100 KHz. (Results will be presented at the ICAE in August 1980.)

**FOCUS OF PRESENT RESEARCH:**

The mechanisms responsible for RF radiation from lightning are important for the development of new sensor techniques and the design of present systems. Research in this area is a long-term commitment of the NASA/GSFC program of research. Recent effort has been directed toward comparing the physical processes responsible for RF and optical radiation and to determining the power spectral density of radiation from lightning at radio frequencies.

PLANS FOR FY81:

The work planned for FY81 will focus on:

o Spectral Measurements: Previous work on first return strokes will be extended to frequencies of several hundred MHz. Events other than return strokes will also be examined and compared with theories which have been developed at Goddard.

o Flash Type Identification: Preliminary results from data collected during TRIP suggest that RF techniques can be used to distinguish flash type. This work will be continued to obtain a quantitative estimate of how well flash type can be identified using the RF signature from space.

o Current in Return Strokes: The modeling work at Goddard and elsewhere suggests the possibility that current pulse shapes may be obtainable from the electric fields radiated during return strokes. Data collected by GSFC to test this possibility are promising for ground-based systems. It is planned to continue this research and look for extensions to spaceborne systems.

o Combined RF and Optical Measurements: A small effort to simultaneously measure high time resolution electric field changes and optical radiation from return strokes will be undertaken.

RECOMMENDATIONS FOR NEW RESEARCH:

Several studies of the problems of detecting RF radiation from space have been made in the past, and satellite experiments have been reported periodically (see table below). A careful review of this past work and the prospects for using existing satellite systems to test concepts would be useful.

Although many things can be done well from the perspective of space, there are advantages to monitoring from the ground. A hybrid system consisting of spaceborne and ground-based sensors might offer the high resolution and detail needed in a domestic warning system, plus the overview needed to address questions of global electrical science. A formal consideration of such a hybrid system is recommended.

Satellite Experiments

| | | |
|---|---|---|
| RF Experiments | | |
| ARIEL-III | 550 KM | 5 to 15 MHz |
| RAE-1 | 6,000 KM | 0.2 to 9 MHz |
| VELA-4B | 110,000 KM | 28 to 42 MHz |
| ISS | 1,100 KM | 2 to 25 MHz |
| Optical Experiments | | |
| OSO-2 & -5 | - | Low Threshold |
| DMSP | 830 KM | Dawn & Dusk |
| VELA | 110,000 KM | Superbolts. |

THUNDERSTORM ELECTRIC FIELDS

Hugh J. Christian, Jr.
ES83 - NASA/MSFC
Huntsville, AL 35812
205-453-2463

We have compared electric field mesurements obtained with the use of balloons and airplanes in an attempt to characterize some of the general features of electric field and charge structure of thunderclouds.

These platforms are mutually complimentary for balloons making soundings through thunderclouds supply information as the vertical distribution of electric fields and charge, however, their slow rise rates can smear temporal and spatial features. Airplane measurements, on the otherhand, provide good spatial resolution, but, because they tend to make horizontal penetrations, information on the vertical electric field structure is poor.

Measurements from a number of different storms suggests that the electric field structure is predominately vertical except near the charge regions. We have commonly measured peaks fields of 100 kV/m and on occasion have detected 150 kV/m fields. We measure vertical fields over long horizontal distances through clouds with the stronger fields in regions where radar reflectivities (above and at the airplane altitude) are in the log Z = 2 to 3 range.

Our studies suggest that the negative charge region has larger horizontal than vertical extent, that it is often centered near the -10 to -15°C isotherm (or approximately 7km msl in New Mexico), contains on the order of -100C, with charge densities greater than -1 nc/m$^3$ and possibly closer to -10 nc/m$^3$. We have much less information on the positive charge region. What we have suggests that it may tend to be centered a couple of kilometers above the negative charge center and that it may be less concentrated.

Simultaneous measurements of electrics fields and precipitation charge and size reveal no simple relationship between drop size and charge and indicate that precipitation is generally locally electrically dissipative below the negative charge center in active storms. We find that precipitation charge densisies which are on the order of a few coulombs per kilometer, are less than but not much less than our estimated total charge density. Charge on individual drops range from less than 10 p coul. (sensitivity limit of the instrument) to greater than 200 with typical values close to 10pc. We suspect that much of the charge may reside on several hundred micron diameter drops.

When we correlate electrical and cloud top height measurements we find that the electrical energy seems to increase primarily during periods of strong vertical growth or is at least strongly coupled with these periods. Further, we suspect that the charge centers remain steady and at a constant altitude during the active period of storms and that they descend as the cloud dissipates.

In 1979, we obtained for the first time balloon and airplane electrical measurements in the same storm. We anticipate that with the analysis of this data, we will achieve better insight into the spatial structure and electrical evolution of thunderclouds.

# APPENDIX A

NASA/MSFC FY-80
ATMOSPHERIC PROCESSES RESEARCH REVIEW
June 3, 4, and 5, 1980

**Tuesday, June 3**

8:30 WELCOME - CHARLES A. LUNDQUIST

I. GLOBAL WEATHER RESEARCH

8:40 Introductory Remarks - WILLIAM VAUGHAN, NASA/MSFC, JOHN THEON, NASA/OSTA

The Spacelab 3 Mission Geophysical Fluid Flow Experiments, JOHN HART, Massachusetts Institute of Technology

Convection Driven by Radial and Latitudinal Temperature Gradients in a Rotating Fluid: Planetary Circulations and GFFC Experiment Planning, DAVID HATHAWAY, NCAR

The Geophysical Fluid Flow Cell Instrument/Spacelab 3 Mission, GEORGE FICHTL, NASA/MSFC

Overview of the Global Atmospheric Flow Model Experiments for Space Flight Program, WILLIAM FOWLIS, NASA/MSFC

BREAK

Laboratory Development Work for the Global Atmospheric Flow Model Experiments Program, WILLIAM FOWLIS, NASA/MSFC

Baroclinic Stability Calculations on a β-Plane and the NCAR Spectral General Circulation Model, JOHN GEISLER, University of Miami

The Effect of Variable Gravity on Baroclinic Instability, ALBERT GIERE, NASA/USRA

Real Hadley Cell Circulations and Their Stability and the Atmospheric General Circulation Experiment Numerical Model, BASIL ANTAR, University of Tennessee Space Institute

Separate and Combined Effects of Shear and Stability Variations in Baroclinic Instability and Boundary Layers and Interior Flows in Rotating Stratified Fluids, JAE HYUN, MSFC/NRC

12:00 LUNCH

A Numerical Axisymmetric Spherical Model and Its Stability and Future Experiments, ROBERT GALL, University of Arizona

A Global View of Global Weather, JOHN DUTTON, Pennsylvania State University

Effect of Latent Heat Release on Global Weather Systems, JOHN CLARK, Pennsylvania State University

Lower Atmosphere Research from Space: Exploratory Study Progress Report, M. H. DAVIS, Universities Space Research Association

Solar-Terrestrial Atmosphere Studies, SHI WU, University of Alabama - Huntsville

SUMMARY COMMENTS - JOHN THEON, NASA/OSTA

II. UPPER ATMOSPHERE RESEARCH

3:20 Introductory Remarks - WILLIAM VAUGHAN, NASA/MSFC, SHELBY TILFORD, NASA/OSTA

AEPI - Atmospheric Emissions Photometric Imager on Spacelab, GARY SWENSON, NASA/MSFC

HRDI - High Resolution Doppler Imager on Spacelab, GARY SWENSON, NASA/MSFC

SUMMARY COMMENTS - SHELBY TILFORD, NASA/OSTA

Wednesday, June 4

I. MESOSCALE/SEVERE STORMS

8:00 Introductory Remarks - WILLIAM VAUGHAN, NASA/MSFC, JAMES DODGE, NASA/OSTA

Ionospheric-Severe Storm Detector, ROBERT SMITH, NASA/MSFC

Enhance Convection Initiated Gravity Waves and Tornado Detection from GOES IR Digital Analysis, RU HUNG, University of Alabama - Huntsville

Acoustic and Gravity Waves in the Ionosphere and the Neutral Atmosphere, NAMBATH BALACHANDRAN, Columbia University

Airborne Doppler Lidar - Severe Storm Systems, JAMES BILBRO, NASA/MSFC

Airborne Doppler Lidar - System, MIKE KRAUSE, Raytheon

BREAK

Scientific Overview of Doppler Lidar Program, GEORGE FICHTL, NASA/MSFC

Analysis of Doppler Lidar Data, JOHN KAUFMAN, NASA/MSFC

Mesoscale/Storm Field Experiments, ROBERT TURNER, NASA/MSFC

Results of AVE-SESAME '79 Data Analysis, TED FUJITA, University of Chicago

Applications of the AVE-SESAME Data Sets to Mesoscale Studies, DAVID SUCHMAN, University of Wisconsin

12:00 LUNCH

Storm-Environment Energetics Determined from AVE-SESAME and Satellite Data, HENRY FUELBERG, St. Louis University

Diagnostic Analysis of the Environment of Severe Storms Using AVE-SESAME and Satellite Data, JAMES SCOGGINS, Texas A&M University

Mesoscale Winds and Rainfall Rates in Areas of Severe Storms Determined From Satellite Imagery and AVE-SESAME Rawinsonde Data, ROBERT JAYROE, NASA/MSFC

Diagnostic Analyses of Important Mesoscale Systems in AVE-SESAME I, KELLY HILL, NASA/MSFC

Mesoscale Structure and Dynamics Relative to Severe Storms, GREGORY WILSON, NASA/USRA

Ageostrophic Circulation-Severe Storms, DONALD JOHNSON, University of Wisconsin

3:00 SUMMARY COMMENTS - JAMES DODGE, NASA/OSTA

II. CLOUD PHYSICS

Introductory Remarks - WILLIAM VAUGHAN, NASA/MSFC, JAMES DODGE, NASA/OSTA

MSFC Cloud Microphysics Program, JEFF ANDERSON, NASA/MSFC

Ice Multiplication, JAMES CARTER, University of Tennessee Space Institute

Gravimetric Verification of Saturator Performance, DAVE BOWDLE, NASA/USRA

Cloud Physics Studies in Low Gravity on the KC-135, VERNON KELLER, NASA/MSFC

Schlieren Studies of Natural Convection from Growing Dendritic Crystals, JOHN HALLETT, Desert Research Institute

International Workshop on Cloud Condensation Nuclei Measurements, WARREN KOCMOND, Desert Research Institute

SUMMARY COMMENTS - JAMES DODGE, NASA/OSTA

8:00 EVENING MIXER SESSION - Special Presentation by TED FUJITA, University of Chicago - New Methods of Predicting Tornado Outbreaks

**Thursday, June 5**

I. ATMOSPHERIC ELECTRICITY (LIGHTNING)

8:00 Introductory Remarks - WILLIAM VAUGHAN, NASA/MSFC, JAMES DODGE, NASA/OSTA

Severe Storm Electricity Overview, DAVE RUST, NOAA/NSSL

Severe Storm Electricity - Storm Intercept, ROY ARNOLD, Mississippi State University

Severe Storm Electricity - Lightning Discharge Mapper, WILLIAM TAYLOR, NOAA/NSSL

Storm Severity Detection (RF), RICHARD JOHNSON, Southwest Research Institute

Remote Observations of Severe Storms, RICHARD ORVILLE, State University of New York - Albany

BREAK

Video Observations of Light Spectra, STUART CLIFTON, NASA/MSFC

Optical Properties of Lightning Detection, BOBBY TURMAN, Air Force Academy, Colorado Springs

Satellite Observations of Lightning During AVE/SESAME '79, BRUCE EDGAR, Aerospace Corporation

Global Lightning Patterns Seen from Satellites, JOHN ELY, University of Washington - Seattle

Experimental Collection of Lightning Emission Data at UHF and SHF, THOMAS SHUMPERT, Auburn University

12:00 LUNCH

Field Mill Development, ROBERT ANDERSON, Navy Research Laboratory, Washington, D.C.

NOSL, BERNARD VONNEGUT, State University of New York - Albany

NOSL - U2, MARX BROOK, Nex Mexico Tech

Nighttime/Daytime Optical Survey of Lightning (NOSL) Experiment, OTHA VAUGHAN, NASA/MSFC

Lightning Mapper - Science and Application Team, ARTHUR FEW, Rice University

Lightning Mapper - RF Sensor Team, PHILIP KRIDER, University of Arizona

Lightning Mapper - Optical Sensor Study Program, WILLIAM WOLFE, University of Arizona

BREAK

Radio Noise and Propagation in Near Space, JOHN HERMAN, Radio Sciences Corporation

Optical Sensor Development Efforts, TOM BARNES, NASA/MSFC

Radio Frequency Lightning Measurements, WARREN HARPER, NASA/MSFC

The Physics of RF Radiation from Lightning, DAVID LEVINE, NASA/GSFC

RF Lightning Research Effort, PHILIP KRIDER, University of Arixona

Thunderstorm Electric Fields, HUGH CHRISTIAN, NASA/MSFC

SUMMARY COMMENTS - JAMES DODGE, NASA/OSTA

CONCLUSION OF RESEARCH REVIEW - WILLIAM VAUGHAN, NASA/MSFC, SHELBY TILFORD, NASA/OSTA

# APPENDIX B

## ATTENDEES

## NASA/ MSFC FY-80 ATMOSPHERIC PROCESSES RESEARCH REVIEW

| NAME | ORGANIZATION | TELEPHONE |
|---|---|---|
| Bob Anderson | Navy Research Laboratory-Washington D.C. | |
| Michael Susko | NASA/Marshall Space Flight Center | (205) 453-3103 |
| Henry Fuelberg | St. Louis University | (314) 658-3121 |
| Gregory S. Wilson | NASA/Marshall Space Flight Center | (205) 453-2570 |
| Martial A. Honnell | Auburn University | (205) 826-4330 |
| Charles A Lundquist | NASA/Marshall Space Flight Center | (205) 453-3105 |
| Dave Dooling | The Huntsville Times | (205) 533-4418 |
| Dick Johnson | Southwest Research Institute | (512) 684-5111 X2765 |
| Authur A. Few, Jr. | Rice University | (713) 527-8101 X3601 |
| William W. Vaughan | NASA/Marshall Space Flight Center | (205) 453-3100 |
| Otha H. Vaughan, Jr. | NASA/Marshall Space Flight Center | (205) 453-5218 |
| R. R. Jayroe | NASA/Marshall Space Flight Center | (205) 453-5609 |
| George S. West | NASA/Marshall Space Flight Center | (205) 453-0941 |
| Robert E. Smith | NASA/Marshall Space Flight Center | (205) 453-3101 |
| Charles F. Schafer | NASA/Marshall Space Flight Center | (205) 453-1886 |
| Kenneth S. Clifton | NASA/Marshall Space Flight Center | (205) 453-2305 |
| William G. Johnson | NASA/Marshall Space Flight Center | (205) 453-3039 |
| Tom Barnes | NASA/Marshall Space Flight Center | (205) 453-1574 |
| E. Philip Krider | University of Arizona | (602) 626-1211 |
| Warren Harper | NASA/Marshall Space Flight Center | (205) 453-4621 |
| Dale Johnson | NASA/Marshall Space Flight Center | (205) 453-3103 |
| Vernon W. Ramsey | NASA/Marshall Space Flight Center | (205) 453-3104 |
| Wayne Wagnon | NASA/Marshall Space Flight Center | (205) 453-4623 |
| John W. Kaufman | NASA/Marshall Space Flight Center | (205) 453-3104 |
| Bill Wolfe | University of Arizona | (602) 626-3034 |
| Dan Fitzjarrald | NASA/Marshall Space Flight Center | (205) 453-1886 |
| David M. LeVine | NASA/Goddard Space Flight Center | (301) 344-8059 |
| Richard E. Orville | State University of New York/Albany | (518) 457-3985 |
| Vernon W. Keller | NASA/Marshall Space Flight Center | (205) 453-0941 |
| Lee W. Parker | Lee W. Parker, Incorporated | (617) 369-1490 |
| W. David Rust | NSSL | (405) 360-3620 |
| Bernard Vonnegut | State University of New York/Albany | (518) 457-4607 |
| James Carter | NASA/Marshall Space Flight Center | (205) 453-5218 |
| David Bowdle | Universities Space Research Association | (205) 453-5218 |
| Nambath Balachandran | Columbia University | (914) 359-2900 |
| Kelly Hill | NASA/Marshall Space Flight Center | (205) 453-2570 |
| William L Taylor | NSSL | (405) 360-3620 |
| David Hathaway | NCAR | (303) 322-5151 X425 |
| John Geisler | University of Miami | (305) 350-7257 |
| Albert Giere | NASA/Marshall Space Flight Center | (205) 453-3104 |
| John Theon | NASA Headquarters | (202) 755-8596 |
| James C. Dodge | NASA Headquarters | (202) 755-8596 |
| Shelby G. Tilford | NASA Headquarters | (202) 755-8596 |
| John R. Herman | Radio Sciences Company | (305) 723-7425 |
| H. W. Hallisey | NASA/Marshall Space Flight Center | (205) 453-2102 |
| George H. Fichtl | NASA/Marshall Space Flight Center | (205) 453-0875 |
| Orvel E. Smith | NASA/Marshall Space Flight Center | (205) 453-3101 |



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## ATTENDEES (CONCLUDED)

| | | |
|---|---|---|
| Hugh Christian | NASA/Marshall Space Flight Center | (205) 453-2463 |
| Bernard J. Anderson | NASA/Marshall Space Flight Center | (205) 453-5218 |
| Robert E. Turner | NASA/Marshall Space Flgiht Center | (205) 453-4175 |
| James W. Bilbro | NASA/Marshall Space Flight Center | (205) 453-1597 |
| Edwin A. Weaver | NASA/Marshall Space Flight Center | (205) 453-1597 |
| James Arnold | NASA/Marshall Space Flight Center | (205) 453-4175 |
| Ted Fujita | University of Chicago | (312) 753-8112 |
| Harold Euler | NASA/Marshall Space Flight Center | (205) 453-2114 |
| John Hart | Massachusetts Institute of Technology | (303) 492-8568 |
| William Fowlis | NASA/Marshall Space Flight Center | (205) 453-2047 |
| Basil Antar | University of Tennessee Space Institute | (614) 455-0631 |
| Jae Hyun | NASA/Marshall Space Flight Center | (205) 453-2047 |
| Robert Gall | University of Arizona | |
| John Dutton | Pennsylvania State University | (814) 455-1534 |
| John Clark | Pennsylvania State University | (814) 723-1581 |
| M. H. Davis | Universities Space Research Association | (303) 449-3414 |
| Shi Wu | University of Alabama-Huntsville | (205) 895-6413 |
| Gary Swenson | NASA/Marshall Space Flight Center | (205) 453-3040 |
| Mike Krause | Raytheon | (617) 443-9521 X3513 |
| David Suchman | University of Wisconsin | (608) 262-5772 |
| Donald Johnson | University of Wisconsin | (608) 262-2538 |
| John Hallett | Desert Research Institute | (702) 972-1676 |
| Bruce Edgar | Aerospace Corporation | (213) 648-5621 |
| John Ely | University of Washington | (206) 543-2633 |
| Glenn Bracken | WAFF-TV 48 | (205) 533-4848 |
| Joanne Simpson | NASA/Goddard Space Flight Center | (301) 344-5948 |
| Bill Shenk | NASA/Goddard Space Flight Center | (301) 344-5948 |
| Charles R. Chappell | NASA/Marshall Space Flight Center | (205) 453-3036 |
| Robert J. Naumann | NASA/Marshall Space Flight Center | (205) 453-0940 |
| Gwenevere Jasper | NASA/Marshall Space Flight Center | (205) 453-1557 |
| Letitia Korbly | NASA/Marshall Space Flight Center | (205) 453-0875 |
| Doug Davis | NOAA/National Weather Service | (205) 772-3521 |
| Charles Prescott | NOAA/National Weather Service | (205) 254-1548 |

# APPENDIX C

# DIABATIC ANALYSIS

## A NEW METHOD FOR PREDICTING TORNADO OUTBREAKS

by

T. Theodore Fujita
The University of Chicago

Prepared for

NASA/MSFC FY-80 Atmospheric Processes Research Review

June 3-5, 1980

Huntsville, Alabama

A B S T R A C T

Basic equations of isentropic analysis were modified into those of diabatic analysis. Test analyses of tornado outbreak situations revealed that diabatic analysis is suitable in depicting both sinking and rising motions lasting 12 to 36 hours. It was found that a downslope wind occurs long before the development of an upslope wind in which mesocyclones form. Analysis works are on the way in an attempt to improve prediction of tornado outbreaks.

## 1. BASIC ELEMENTS OF TORNADO OUTBREAKS

**It has been known that strong and violent tornadoes are spawned by rotating thunderstorms associated with mesocyclones. The basic elements of tornado outbreaks, therefore, are those which give rise to the formation of rotating thunderstorms.**

Basic elements related to the formation of supercell, rotating thunderstorms are: --

A. Upper-air Divergence ---- Significant divergence at the 200 to 300-mb jet-stream levels.

B. Lower Convergence ---- Lateral convergence associated with low-level jet.

C. Lifted Index ---- A measure of static instability of rising parcel.

D. Low-level Moisture ---- High mixing ratio or dew-point temperature in the lowest 2,000 to 3,000 ft.

E. Field of Rotation ---- Large absolute vorticity inside the inflow layer.

When these elements are amalgamated into a boiling pot, supercell tornadoes will pump low-level moisture up into the jet-stream levels. Huge rotating supercell storms, thus created, will spawn outbreak tornadoes. Figure 1 shows a flow diagram in which vorticity and instability are combined into the formation of rotating thunderstorms.

Constant-pressure charts, currently in use at most forecast offices, often show a significant PVA (positive vorticity advection) at 500 mb prior to a tornado outbreak. Meanwhile, an MAA (moist-air advection) intensifies in advance of a PVA.

In effect, the mid-level cooling and the low-level warming, along with the moisture influx, increase the INSTABILITY shown in Figure 1. ABSOLUTE VORTICITY at the low-level increases, because of the development of a surface low in advance of the PVA.

The processes of increasing both absolute vorticity and instability can also be explained by depicting the airflow on a potential temperature surface. Such a surface cuts through a number of constant-pressure surfaces. Both downslope and upslope winds can be described effectively on the surface with considerable slopes.

Analyses of a number of situations revealed that a pocket of downslope wind is located near a significant PVA and that a tongue of upslope wind, near an MAA.

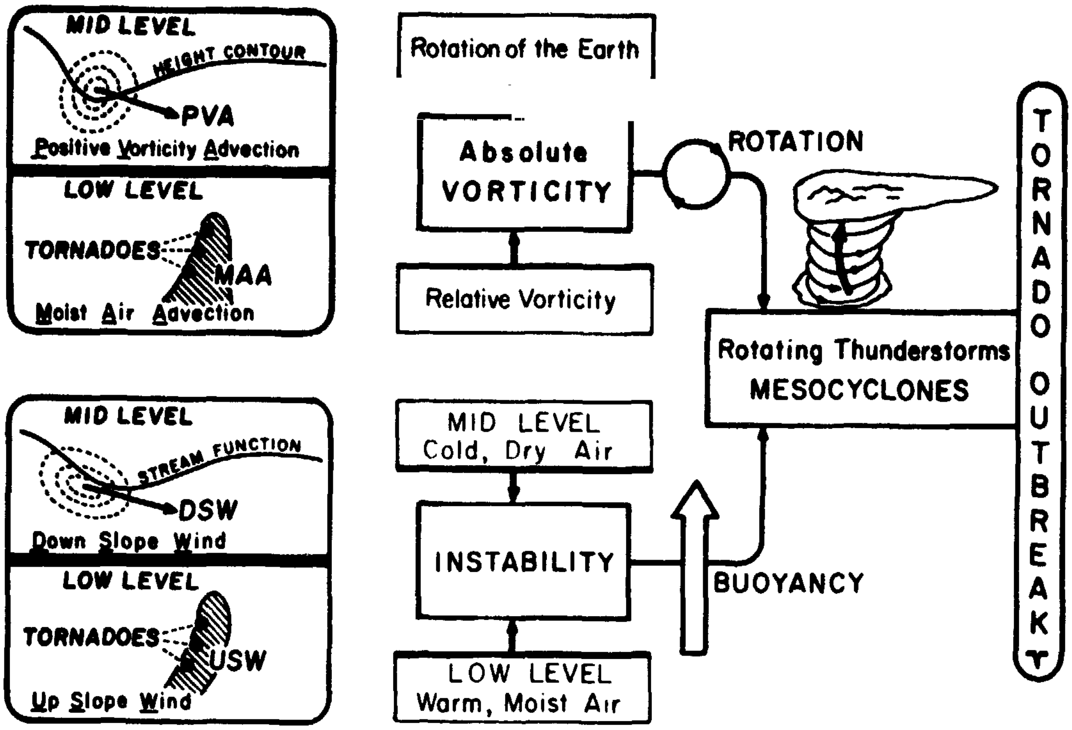


Figure 1. A flow diagram showing combined effects of INSTABILITY and VORTICITY which give rise to the formation and development of rotating thunderstorms. Rotating thunderstorms often identified as hook echoes, supercells, and mesocyclones spawn destructive tornadoes.

It has been found that a downslope wind (DSW) forms 24 to 36 hours prior to a tornado outbreak, while an upslope wind (USW) is induced 12 to 24 hours later. This encouraging evidence has led to a conclusion that the depiction of DSW and USW on a potential temperature surface is very useful in predicting tornado outbreaks with a 24- to 36-hour lead time.

## 2. ISENTROPIC AND DIABATIC PROCESSES

Isentropic analyses initiated notably by Rossby, et. al. (1937), Montgomery (1937), Byers (1938), and Namias (1938) were pursued by Oliver and Oliver (1951), Bjerknes (1951), Saucier (1955) and others. General interest in isentropic analysis, nonetheless, diminished during the late 1950s, because of time-consuming analyses with insignificant benefits to most forecasters.

A gradual comeback of isentropic analysis started in the mid to late 1970s, after about 20 years. Bleck (1975), Marks and Jones (1977), and Petersen (1979) demonstrated that objective analyses of isentropic charts can be achieved quickly and economically.

In requesting "Research Rapid Scan Days" for SMS/GOES east and west satellites, the author was faced with the problem of predicting tornado outbreaks of Spring, 1980 24- to 36-hours in advance. For this purpose, a series of daily isentropic analyses was performed at the University of Chicago in March and April, 1980. These isentropic analyses led to the following findings: --

A. An initial descending motion takes place at or above the 500-mb height.

B. Taking 24 to 36 hours, the cold descending air reaches near the ground.

C. The isentropic potential temperature decreases slightly during the slow descent, taking over a day.

It is very likely that the downslope wind does not warm up as much as the isentropic processes specify. Instead, the descending pocket of air is losing its internal energy through radiation, mixing, and other exchange processes.

Figure 2 shows schematically a diabatic descent of a downslope wind from 500 mb to the surface. If the descent is strictly adiabatic, -25°C at 500 mb should warm up to 0°C at 700 mb, to +15°C at 850 mb, and to +29°C at 1000 mb. An upslope wind on the advancing side of the diabatic descent should also be diabatic -- or could be more diabatic due to the release of latent heat in clouds.

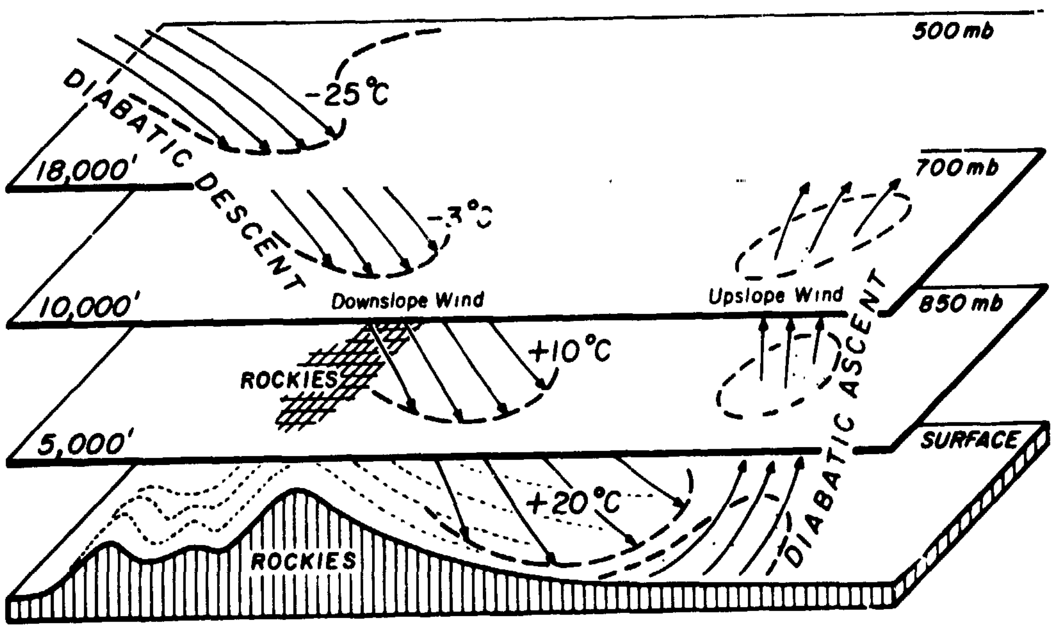


Figure 2. Schematic diagram of airflow undergoing the diabatic ascent induced by a diabatic descent. During diabatic processes, a descending parcel loses heat while an ascending parcel gains heat energy.

As a first step in formulating diabatic motions, taking one to two days, a following assumption has been made.

$$dQ = dU + dW \tag{1}$$

$$dQ = -\alpha dU \quad \text{(diabatic)} \tag{2}$$

where $\alpha$ is a positive constant called the "diabatic constant". The diabatic constant is zero when the process is adiabatic.

The equations in Figure 3 show that this simplified diabatic process can be formulated by defining "diabatic potential temperature" which corresponds to "isentropic potential temperature".

$$\boxed{dQ = dU + dW}$$

| ISENTROPIC | DIABATIC |
|---|---|
| $0 = dU + dW$ | $-\alpha dU = dU + dW$ |
| $P\,T^{-\frac{C_p}{R}} = \text{Const.}$ | $P\,T^{-\frac{C_p + \alpha C_v}{R}} = \text{Const.}$ |
| Isentropic Potential Temp. | Diabatic Potential Temp. |
| $\theta = T\left(\frac{P}{1000}\right)^{-\frac{R}{C_p}}$ | $\phi = T\left(\frac{P}{1000}\right)^{-\frac{R}{C_p + \alpha C_v}}$ |
| Isentropic Stream Function | Diabatic Stream Function |
| $f\,V_g = \left(\frac{\partial \psi}{\partial n}\right)_\theta$ | $f\,V_g = \left(\frac{\partial \zeta}{\partial n}\right)_\phi$ |
| $\psi = C_p T + gH$ | $\zeta = (C_p + \alpha C_v)T + gH$ |
| $\Psi = \frac{\psi}{g} = (H + \frac{C_p}{g} T)$ | $Z = \frac{\zeta}{g} = (H + \frac{C_p + \alpha C_v}{g} T)$ |

Figure 3. Basic equations of diabatic parameters obtained by the author early in 1980.

The Montgomery stream function is the special case of "diabatic stream function" which can be expressed by the function, Z, in meters. A diabatic chart will include

* Wind vector, ddff, on a specific diabatic potential temperature surface.

* Stream function, Z, which is contoured as if it were the height on a constant pressure chart. A contour interval of 30 or 60 m is preferable.

* Diabatic pressure, P, contoured in dashed lines like isotherms on a constant-pressure chart. Contour interval is 50 or 100 mb.

The following constants are used in computing diabatic equations in Figure 3.

$$R = 2.87 \times 10^{6} \ \text{erg} \ g^{-1} \ {}^{\circ}K^{-1}$$

$$C_v = 5/2\ R = 7.175 \times 10^{6} \ \text{erg} \ g^{-1} \ {}^{\circ}K^{-1}$$

$$C_p = 7/2\ R = 10.045 \times 10^{6} \ \text{erg} \ g^{-1} \ {}^{\circ}K^{-1}$$

$$\frac{C_p + \alpha C_v}{R} = \frac{7 + 5\alpha}{2}$$

$$\frac{C_p + \alpha C_v}{g} = 102.6 + 73.2\alpha \ \text{meter} \ {}^{\circ}K^{-1}$$

Numerical values of diabatic potential temperature surfaces with -25 C temperature at 500 mb are presented in Tables 1 and 2.

Table 1. Temperature ( °C and °K) of isentropic and diabatic surfaces which intersect the 500-mb pressure height with -25°C isotherms.

| | Mandatory Pressures | | | | | |
|---|---|---|---|---|---|---|
| | 300 | 400 | 500 | 700 | 850 | 1000 mb |
| $\alpha = 0.0$ | -58.7 | -40.3 | -25.0 | 0.0 | +15.6 | +29.3°C |
| | 214.5 | 232.8 | 248.1 | 273.2 | 288.8 | 302.5°K |
| $\alpha = 0.1$ | -56.6 | -39.4 | -25.0 | -1.7 | +12.7 | +25.3°C |
| | 216.5 | 233.8 | 248.1 | 271.4 | 285.8 | 298.5°K |
| $\alpha = 0.2$ | -54.8 | -38.5 | -25.0 | -3.2 | +10.2 | +21.9°C |
| | 218.4 | 234.7 | 248.1 | 269.9 | 283.4 | 295.1°K |

Table 2. Values of $\Psi - H$ and $Z - H$ for mandatory pressure heights. Isentropic and diabatic stream function can be obtained by adding the height of the isentropic surface to the numbers in this table. (Unit in 10 meters)

| | Mandatory Pressures | | | | | |
|---|---|---|---|---|---|---|
| | 300 | 400 | 500 | 700 | 850 | 1000 mb |
| $\alpha$ = 0.0 | 2201 | 2389 | 2546 | 2803 | 2963 | 3104 x 10 m |
| $\alpha$ = 0.1 | 2380 | 2570 | 2727 | 2983 | 3141 | 3281 x 10 m |
| $\alpha$ = 0.2 | 2560 | 2752 | 2909 | 3164 | 3322 | 3460 x 10 m |

## 3. ENERGY CASCADE

Diabatic analysis of tornado outbreak situations revealed a cascade of energy from the general circulation-scale down to the tornado scale. Evidently, the downslope wind plays a key role in accomplishing the cascade of energy (see Figure 4).

The initial formation of a downslope wind takes place to the west or northwest of the Rockies at 300- to 500-mb heights, 12 to 24 hours prior to the onset of the upslope wind. At this point, the cause and effect relationship between upslope and downslope winds is evident; a downslope wind, which originates first, induces an upslope wind.

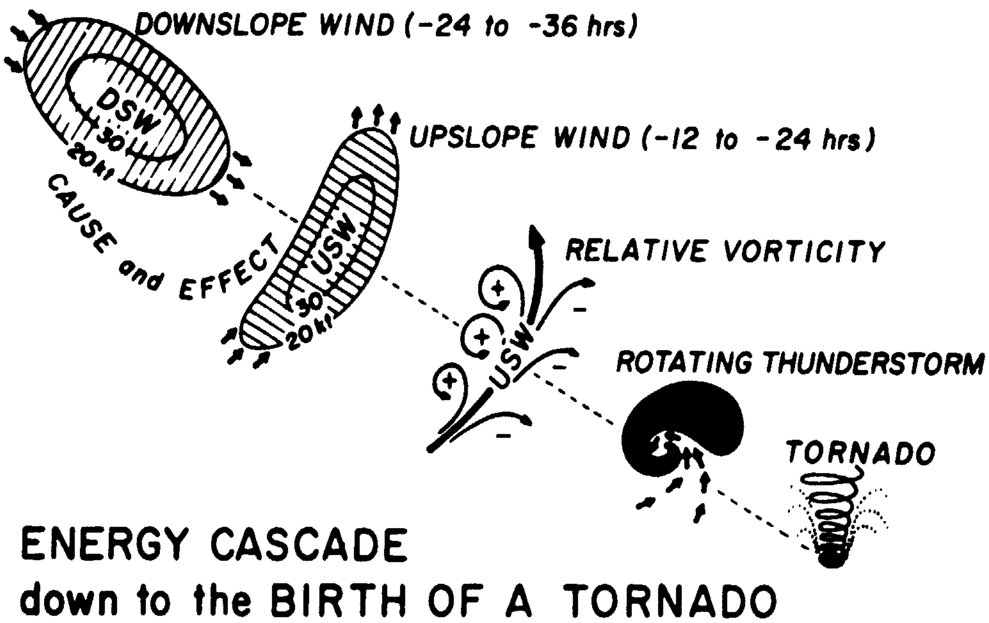


Figure 4. Energy cascade from downslope wind, rotating thunderstorm, finally to tornado.

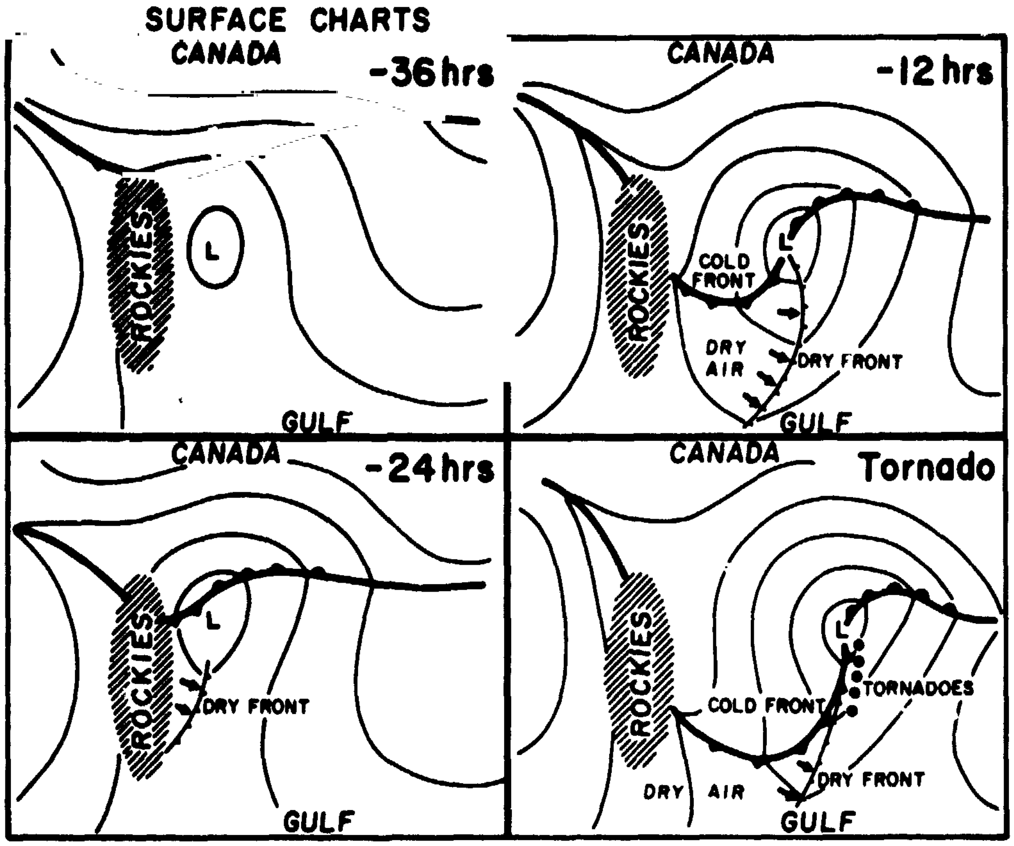


Figure 5. Four surface charts at 12-hour intervals prior to an outbreak of tornadoes. Tornadoes often form ahead of cold front.

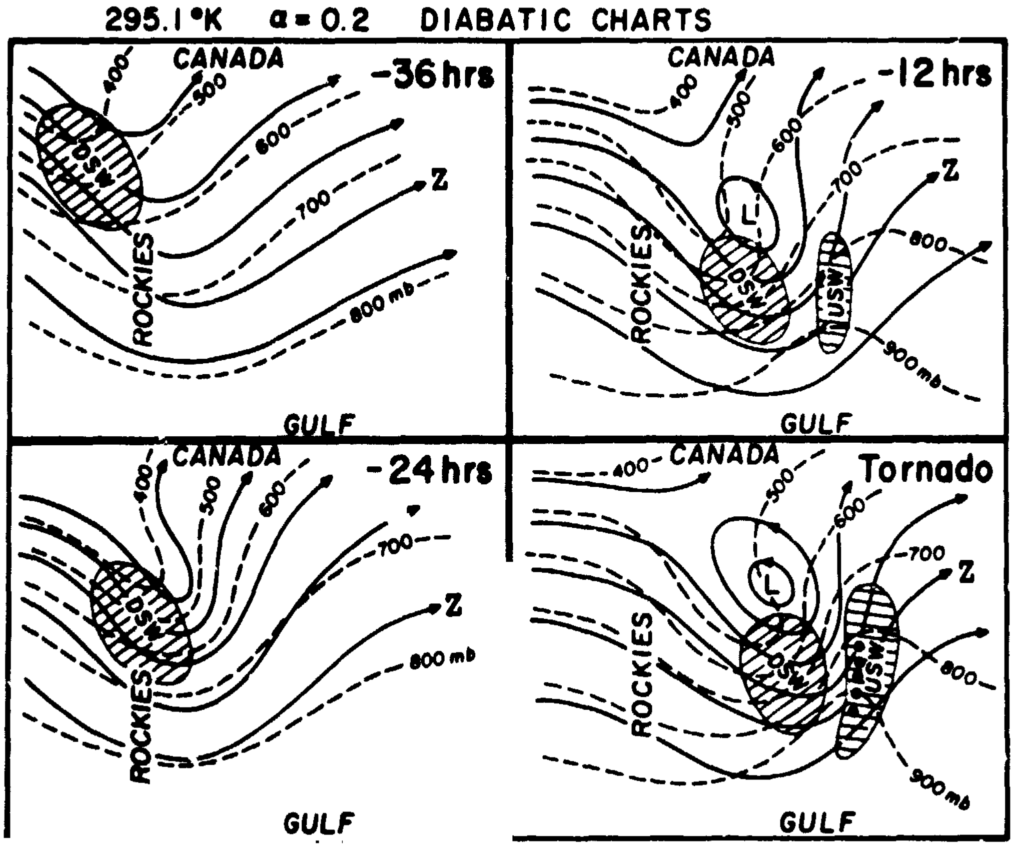


Figure 6. Four diabatic charts at 12-hour intervals corresponding to the surface charts in Figure 5. These charts show that a down-slope wind from the northwest is an excellent predictor.

Apparently, the downslope wind, during its long-distance descent, generates positive vorticity on the left (northeast) side. By the time the downslope wind reaches the low level, a significant vorticity field appears at all levels. Thus, a PVA takes place in the immediate area of the downslope wind.

The transformation of energy leading to the development of upslope wind is achieved by the downslope wind which descends with its large momentum brought down from its initial altitude. The downslope wind, in effect, contributes to the cyclogenesis throughout the entire depth of the troposphere.

A significant upslope wind results in warm advection at low levels. Meanwhile, the field of intense vorticity on the left side of the upslope wind provides thunderstorms with cyclonic circulations required to develop these storms into rotating thunderstorms, supercells, mesocyclones, or hook echoes. It has been known that rotating thunderstorms, during their lives, are the mother clouds that spawn strong and violent tornadoes.

A time sequence of the event which leads to a tornado outbreak is presented in Figures 5 (surface chart) and 6 (diabatic chart). The surface charts imply that an outbreak of tornadoes occurs along the leading edge of the cold air from Canada as it pushes violently eastward.

Diabatic charts, on the other hand, depict an area of downslope wind heading toward the Rockies some 24 to 36 hours in advance of a tornado outbreak. As the downslope wind passes over the Rockies, cyclogenesis takes place on the east side of the Rockies.

It should be noted that the upslope wind at -12 hrs is located on the advancing side of the downslope wind which is dry and quite often warmer than the warm, moist air on or near the ground. The cold front of Canadian air is located far behind the dry front which signifies the leading edge of the downslope wind.

The cold front may or may not overtake the dry front prior to the onset of a tornado outbreak. If it does, a line of tornadoes will develop along the cold front; if it does not, a tornado outbreak occurs way ahead of the cold front.

## 4. EFFECT OF TIBET UPON TORNADOES IN CHINA

A series of diabatic charts analysed by the author seems to indicate that the cold front located in the vicinity of a tornado outbreak is of secondary importance upon its outbreak. In other words, an active cold front may not be required in order to set off an outbreak. Instead, a significant downslope wind and associated upslope wind seem to play an important role upon the onset.

Surface and upper-air charts over China were analysed for testing this hypothesis. Tornadoes are known to be rare and weak in China while cold fronts are strong and frequent there.

The topographic environment of east-central China is similar to that of the United States Midwest. There are high mountains to the west and warm tropical waters to the south.

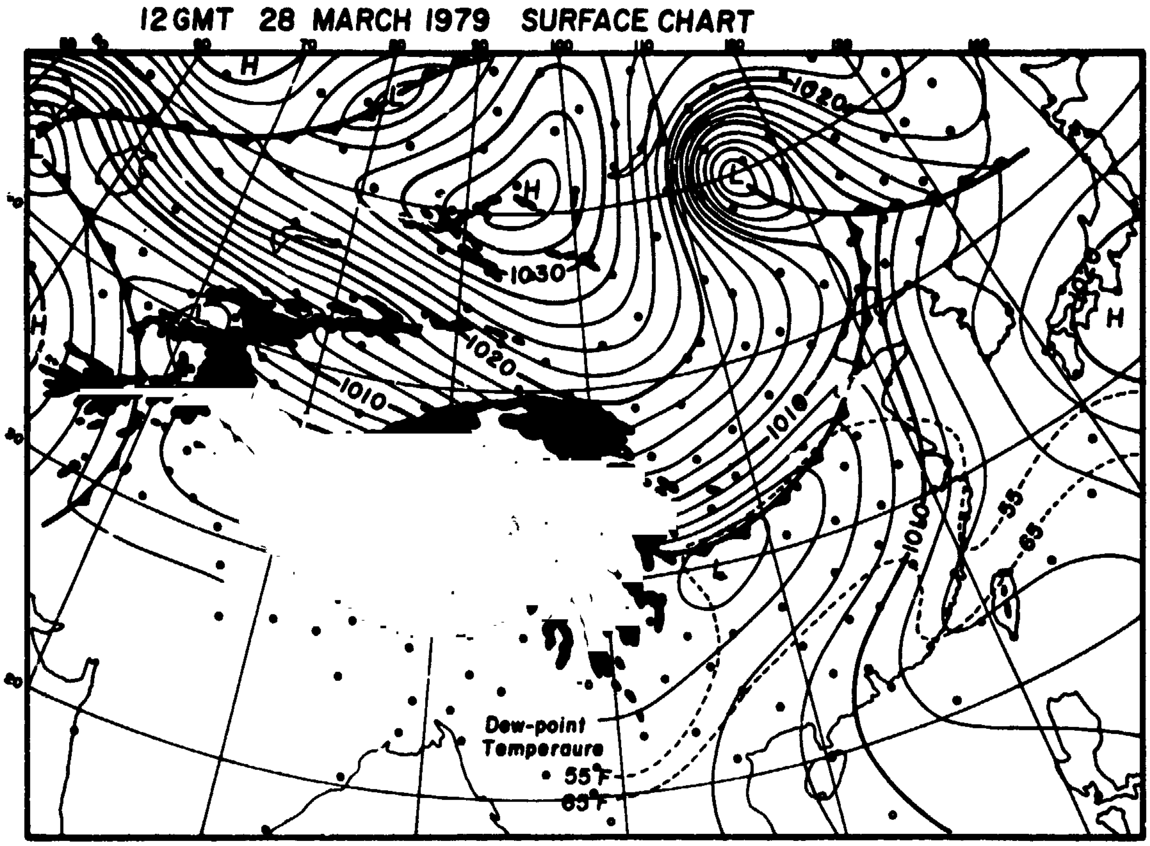


Figure 7. A cold front over China.

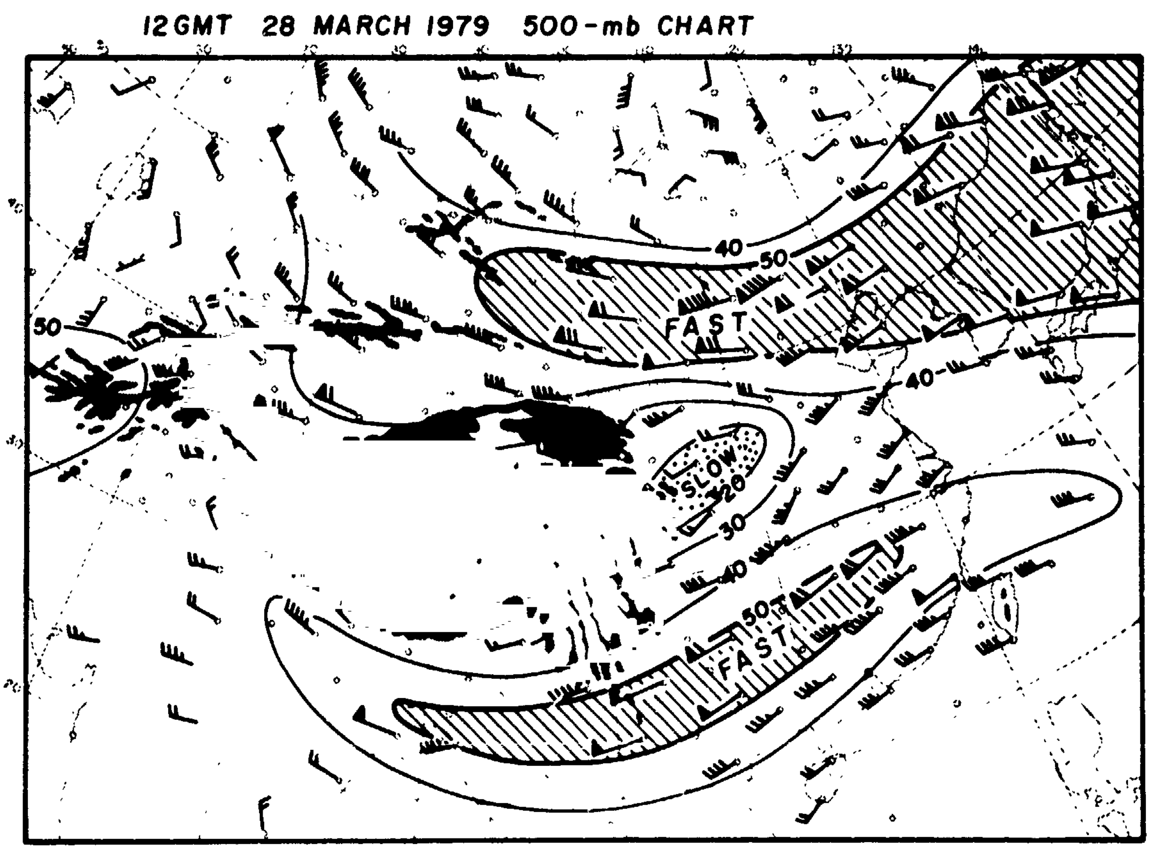


Figure 8. Split of westerlies caused by the highland of Tibet.

Figure 7 is a surface chart at 12 GMT on March 28, 1979, showing an example of a well-developed cold front extending from the Yellow Sea to the eastern edge of Tibet. If a frontal situation similar to this chart prevails over the United States in Spring, a number of damaging tornadoes are expected to occur, resulting in a few tornado watch boxes. In China, however, tornado outbreaks are rare or nonexistent. What is the major difference in synoptic situations?

Figure 8 shows a 500-mb chart which corresponds to the surface map of Figure 7. As seen clearly in this chart, the highland of Tibet splits the westerlies into northern and southern streams. The southern stream with up to 60 kt wind extends from northern India to Okinawa, while the northern stream extends from Gobi to the Sea of Japan.

In the downstream of Tibet, between the northern and southern streams, there is a weak, stagnation flow with winds up to only 20 kt at 500 mb. As expected, a more significant stagnation and split flow is seen at 700 mb. It is very likely that a combination of orographic and thermal effects of Tibet alters the upper-air flow over eastern China completely.

Apparently, Tibet is much higher and larger than the Rockies. Proper-sized mountains, such as the Rockies, do enhance tornado activities. The highland of Tibet, on the other hand, splits the westerly flow into two, thus eliminating the possibility of a significant downslope wind entering into the east China plain from the west or northwest. If mountains are too high and extensive, their presence suppress tornado activities. It would be useful to investigate the possible effects of Tibet upon weather and climate of eastern China and western Japan.

The unique feature of Tibet is its large body of relatively flat plateau attached to the Pamirs, something like a tail extending westward. The Pamirs, known as the roof of the world, is connected to folded mountains with a large number of roughness fins sticking out toward the northwest. These fins are likely to reduce the flow speed of the north branch of the split flow (see Figure 7).

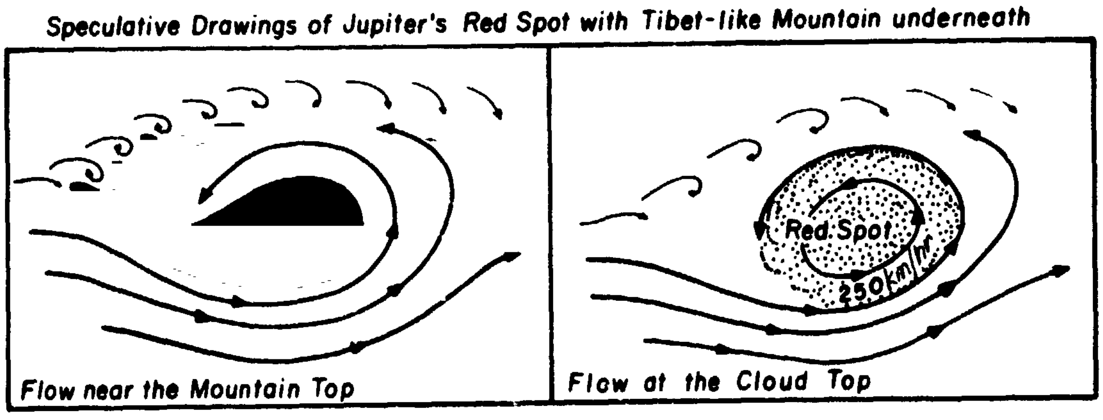


Figure 9. Is there Tibet-like highland beneath Jupiter's Red Spot, a giant swirl of 250 to 280 km/hr.

If the southern edge of the Himalayas was polished smooth, the south branch of the split flow will be accelerated by the Bernoulli effect without friction. The cyclonic flow, thus generated, could circle around the east edge of Tibet inducing a large cyclone.

The purpose of speculating on a possible mechanism of Jupiter's Red Spot is to emphasize the effect of a super-mountain/plateau, such as Tibet, upon an impinging current (see Figure 9).

## 5. DIABATIC ANALYSIS OF SESAME-79 DATA

AVE-SESAME sounding data on April 10, 1979, the day of the Wichita Falls tornado, were analysed in detail. Presented herewith are examples of diabatic analyses with 295 °K potential temperature.

Figure 10 was prepared to show a downslope wind, in excess of 30 kt, descending over California heading toward New Mexico. An upslope wind began intensifying over southeastern Texas. Time: 6 a.m. April 10, 1979, some 12 hours before the Wichita Falls tornado.

Three hours before the tornado (see Figure 11), the downslope wind reached over the Arizona-New Mexico border. Upslope wind moved up with its axis extending from the Red River valley to near Omaha, Nebraska. A couple of tornadoes occurred on the left (cyclonic) side of the upslope-wind axis.

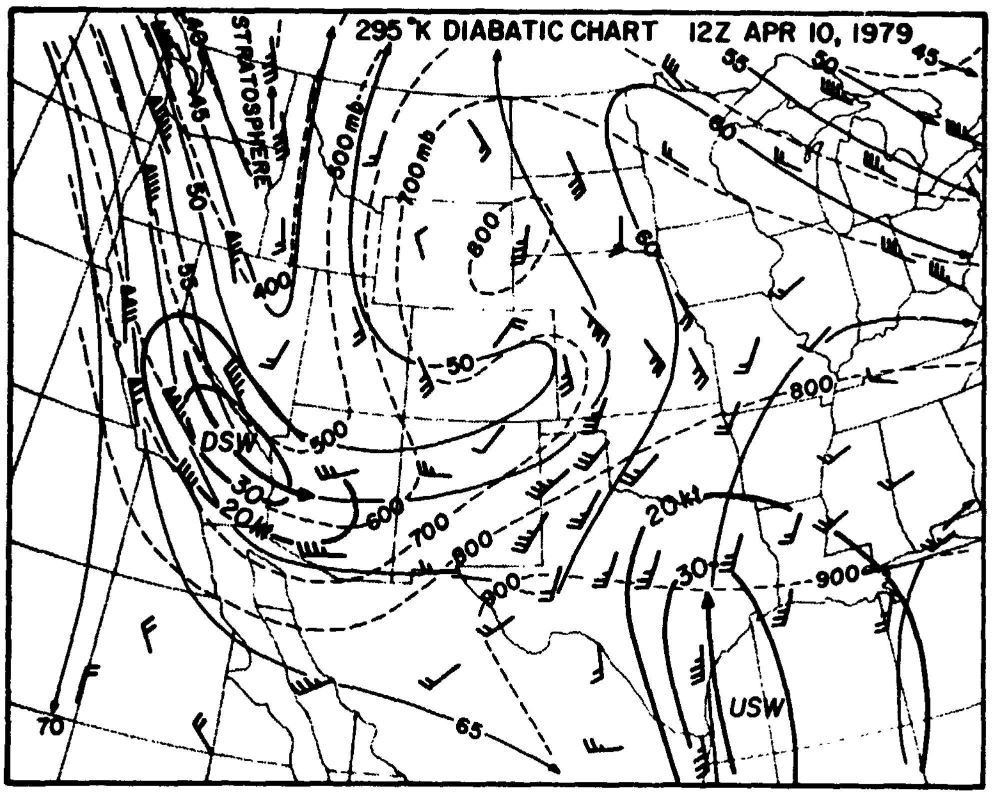


Figure 10. Diabatic chart 12 hours before the Wichita Falls tornado.

295°K DIABATIC CHART 21Z 3p.m. 10 APR 1979

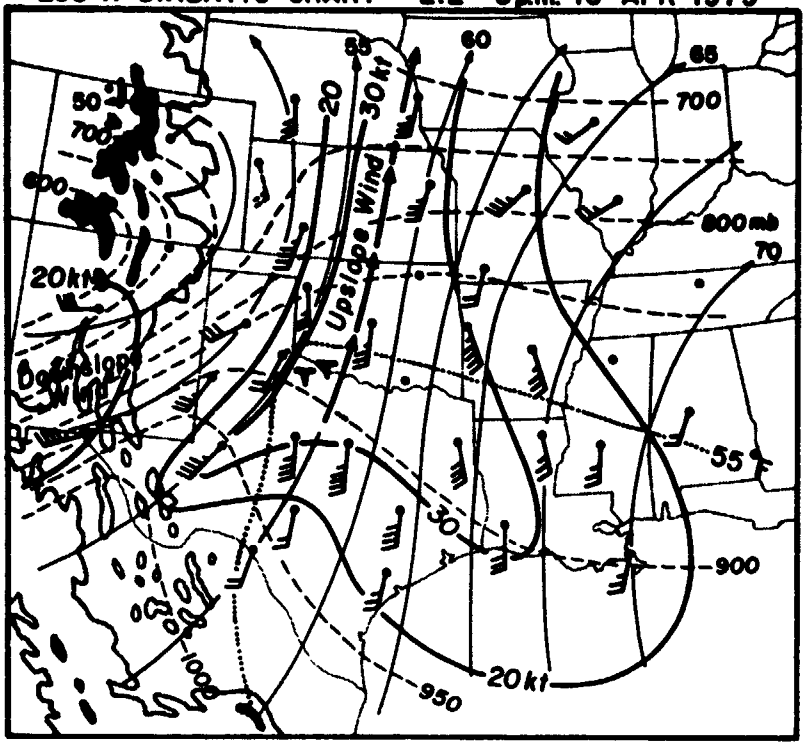


Figure 11. Local diabatic chart 3 hours before the tornado.

295°K DIABATIC CHART 00Z 6p.m. 10 APR 1979

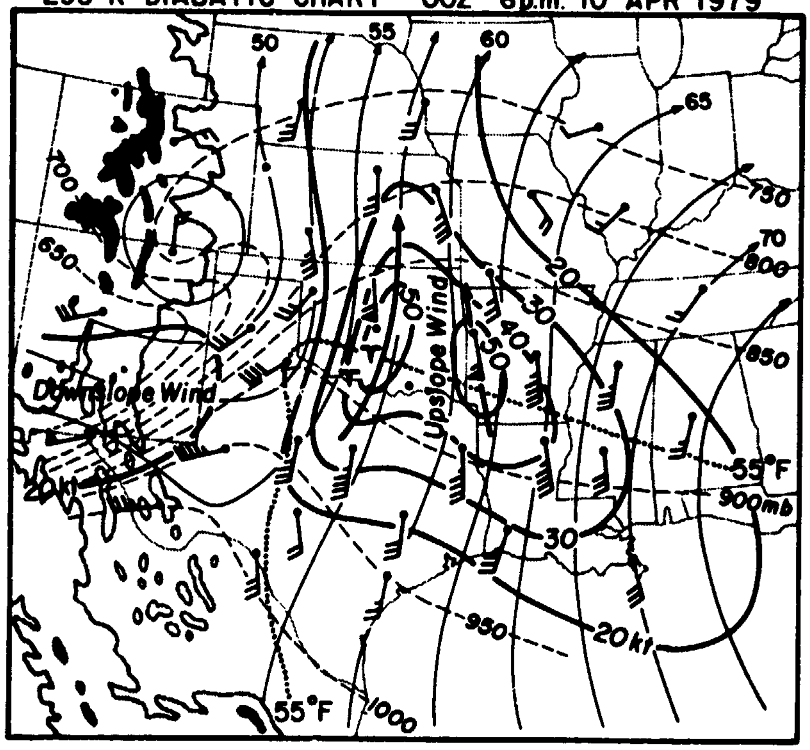


Figure 12. Local diabatic chart at the time of the tornado.

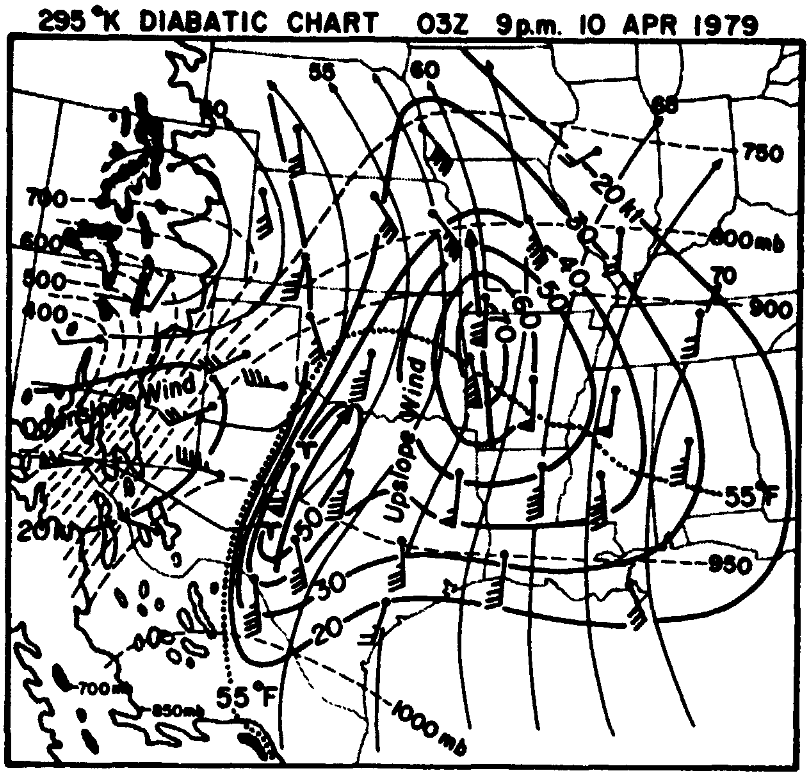


Figure 13. Local diabatic chart 3 hours after the tornado.

When the Wichita Falls tornado occurred at about 6 p.m. (see Figure 12), the downslope wind over New Mexico was strong. The tornado occurred on the left (cyclonic) side of the upslope-wind axis.

Three hours after the Wichita Falls tornado, a new upslope wind developed on the advancing side of the downslope wind. Weak night-time tornadoes were reported in central Texas.

## 6. CONCLUSIONS

The diabatic analysis presented in this paper is designed to be identical, in procedures, to isentropic analysis familiar to meteorologists for the last five decades. Vertical velocities of both isentropic and diabatic flows cannot be computed without subtracting the isobar movement. Nonetheless, steeper slope of the diabatic surface, in comparison with isentropic surface, allows us to depict upslope and downslope winds effectively.

It is recommended that this proposed diabatic analysis be tested further in order to improve early prediction of tornado outbreaks. Specific recommendations are: --

A. To carry out AVE experiments over the western parts of the United States to investigate the nature of downslope wind, a new predictor of tornado outbreaks.

B. To develop Severe-Storm and Mesoscale Environmental Research Satellite (SMEARS) with improved sounding capabilities in the presence of high clouds. Such a satellite is extremely useful in detecting and tracking a downslope wind from the northeastern Pacific to the immediate vicinity of tornado areas.

C. To pursue diabatic analyses over the other parts of the world to determine the influence of giant mountains. The highland of Tibet appears to be the best orography to be studied.

D. To conduct global analyses of diabatic charts in describing three-dimensional motions of the global atmosphere.

**ACKNOWLEDGEMENT:**

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# APPROVAL

# NASA/MSFC FY-80 ATMOSPHERIC PROCESSES RESEARCH REVIEW

Compiled by Robert E. Turner

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

William W Vaughan

WILLIAM W. VAUGHAN
Chief, Atmospheric Sciences Division

Charles A. Lundquist

CHARLES A. LUNDQUIST
Director, Space Sciences Laboratory



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